Search for gluinos and squarks with Missing Energy plus multijets CDF (Run Ib) data

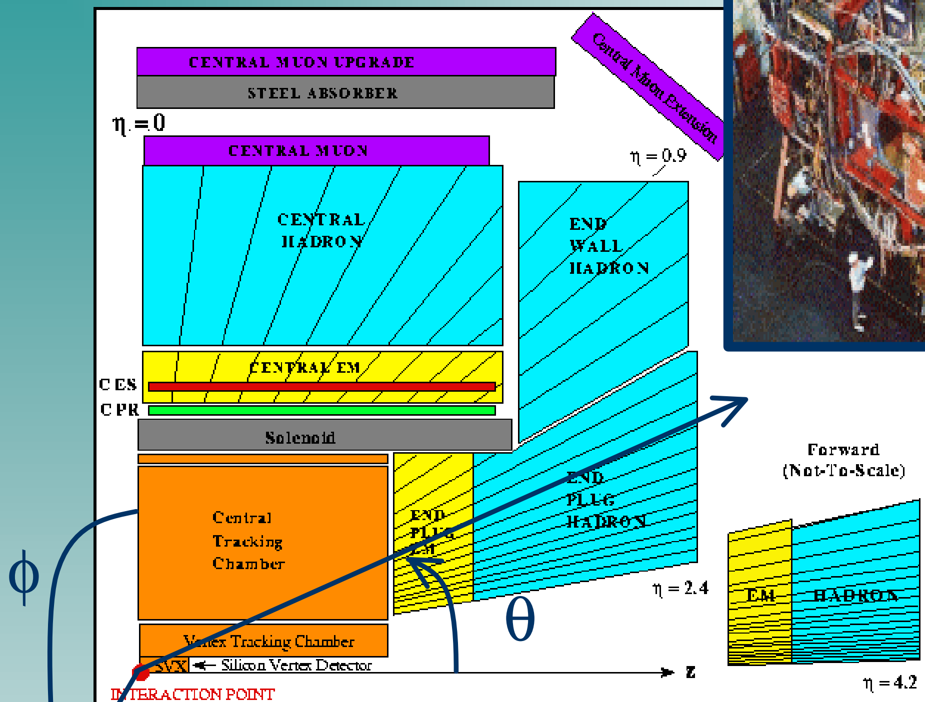
Maria Spiropulu

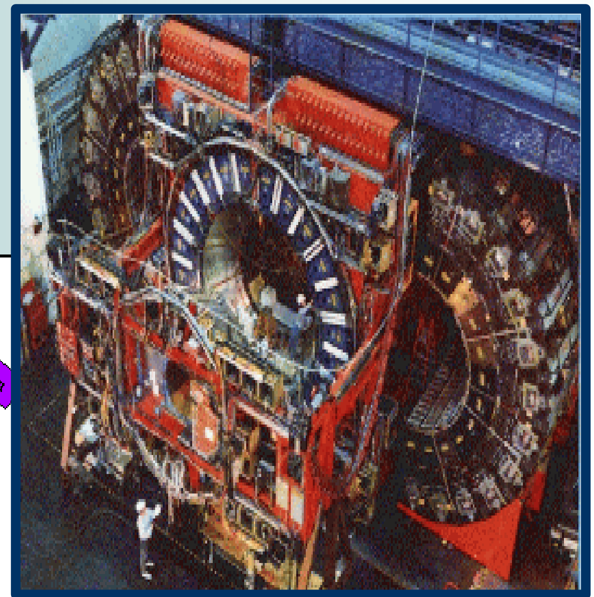
EFI/UofC

Nov 3 2000

FNAL W&C

Missing E_T





$$\vec{E}_T + \sum \vec{E}_T = \vec{0}$$

$$h = -\log(\tan\frac{q}{2})$$

$$-4.2 < h < 4.2$$

$$\begin{pmatrix} E^x{}_T = -\sum_i E^i{}_T \cos(q_i) \\ E^y{}_T = -\sum_i E^i{}_T \sin(q_i) \end{pmatrix}$$

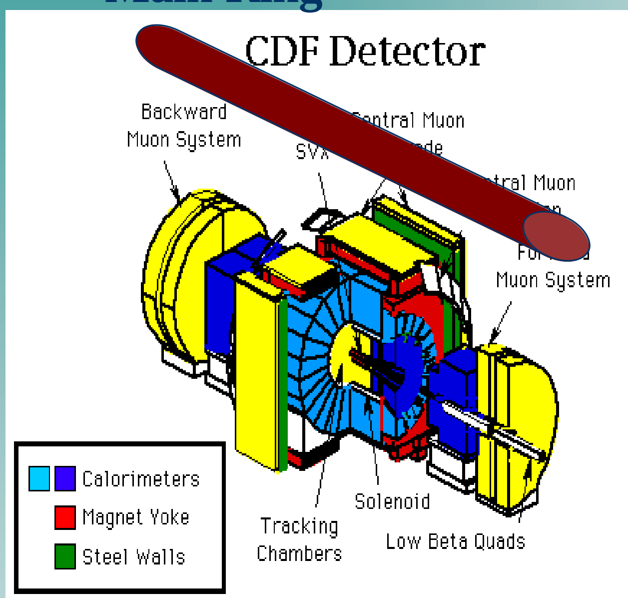
Missing Energy provides the classic R-parity conserving SUSY signature (R=(-1)$^{3B+L+2S}$) but appears in many other phenomenological paradigms

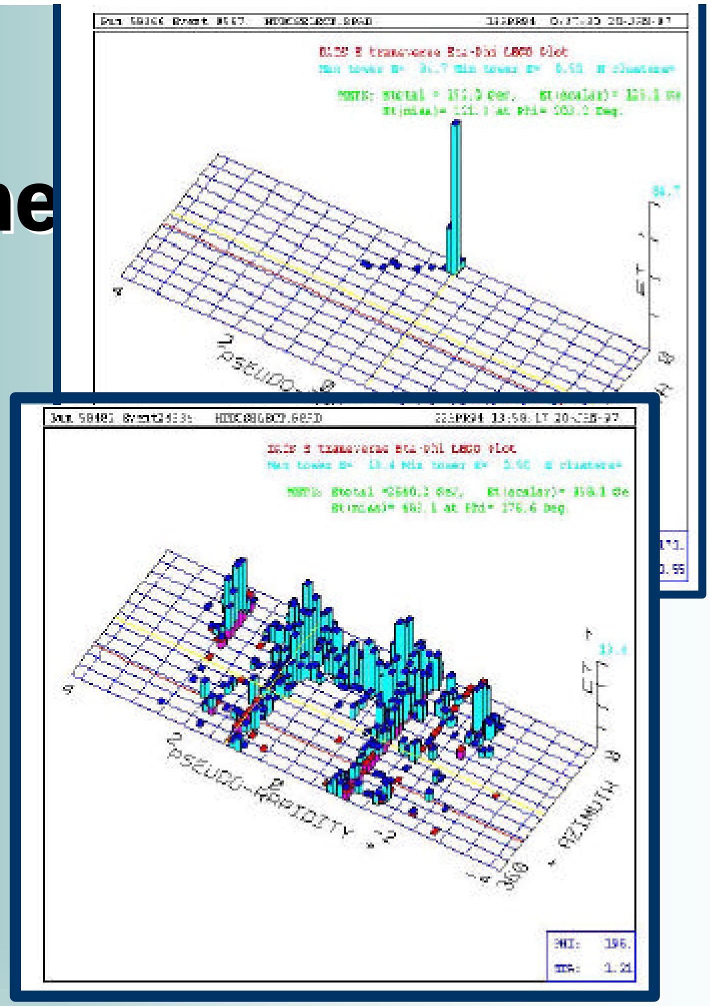
MET + 3 jets (squarks,gluinos) , MET + c-tagged jets (scalar top)

MET + b-tagged jets (scalar bottom,Higgs), MET + monojet (gravitino, graviton) MET + photons (gravitino)

Fake Missing Ene

Main Ring



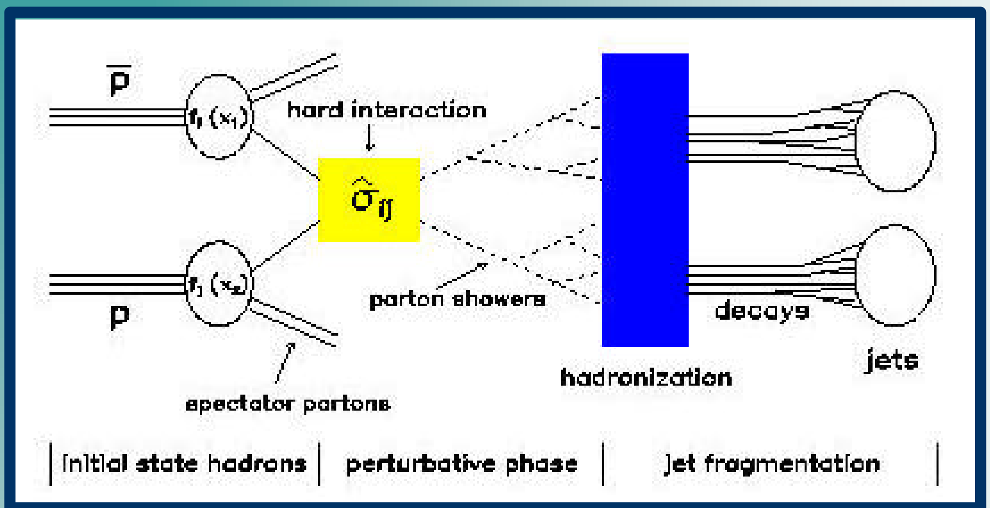


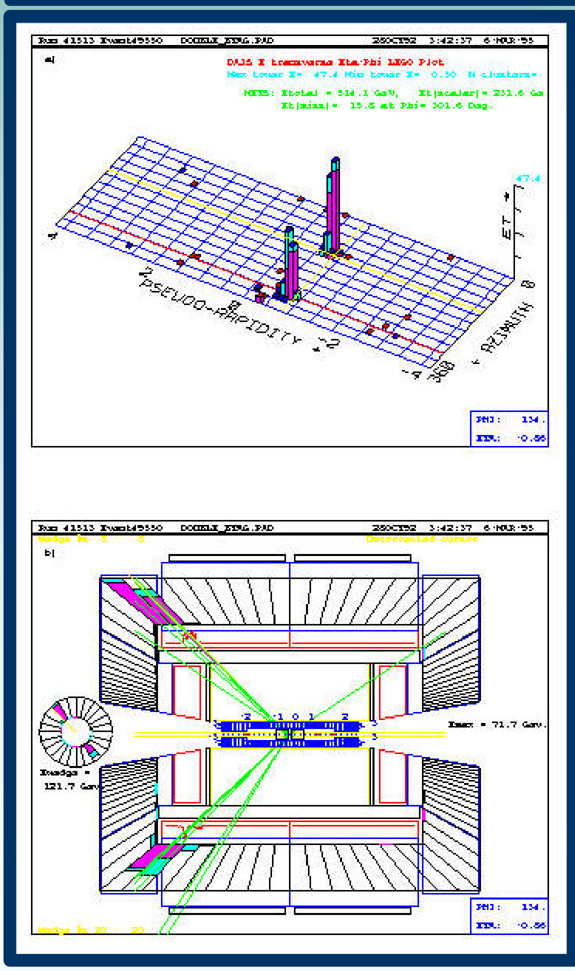
INSTRUMENTAL SOURCES OF MISSING ENERGY

MAIN RING
DETECTOR MALFUNCTIONS/NOISE
COSMICS

These are eliminated with a set of timing and good jet quality requirements

Jets



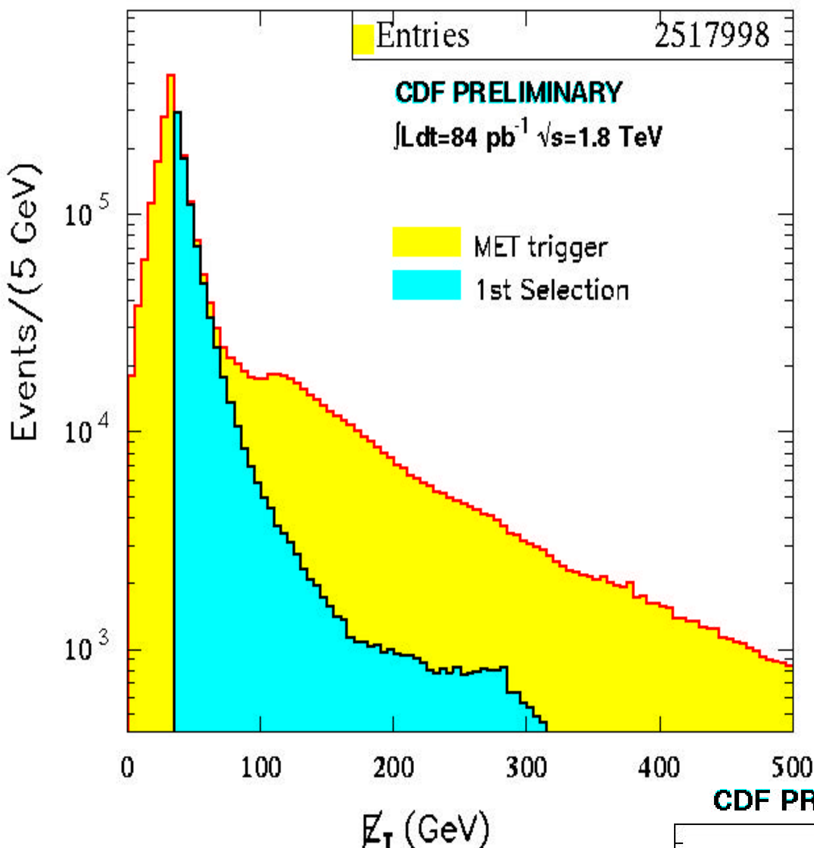


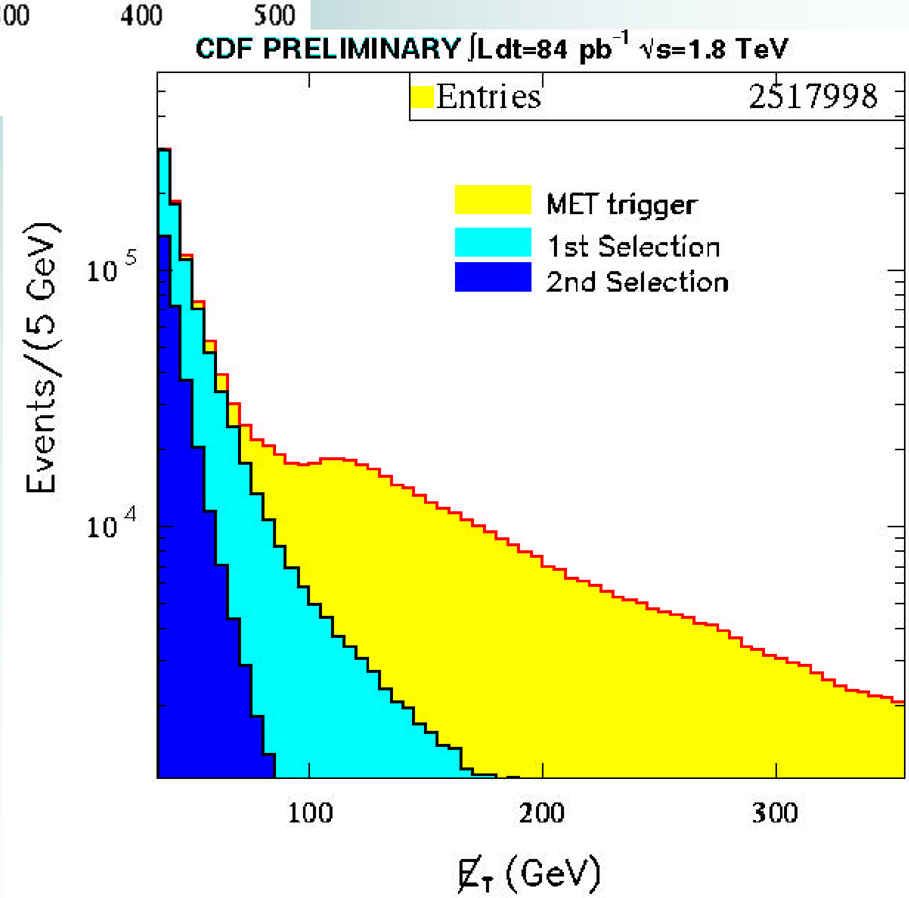
Jet variables used for "good jetiness" criterion:

* **Charge Fraction (CHF)**

* **EM fraction (EMF)**

DATA PRE-SELECTION





DATA PRE-SELECTION

of 2517998 events	Number of events fail
$\not{E}_T$	1123734
Out-Time	506241
Stage 1 $= \not{E}_T \oplus$ Out-Time	1625603
Total passing Stage 1	892395

of 892394 events	Number of Events Fail
1 central jet	372978
EEMF	24992
ECHF	591449
Total passing Stage 2	300945

MISSING ENERGY + MULTIJET STANDARD MODEL COMPONENT

$Z(\rightarrow ll)$ + jets

$W(\rightarrow l\nu)$ + jets

$t\bar{t}$, single top

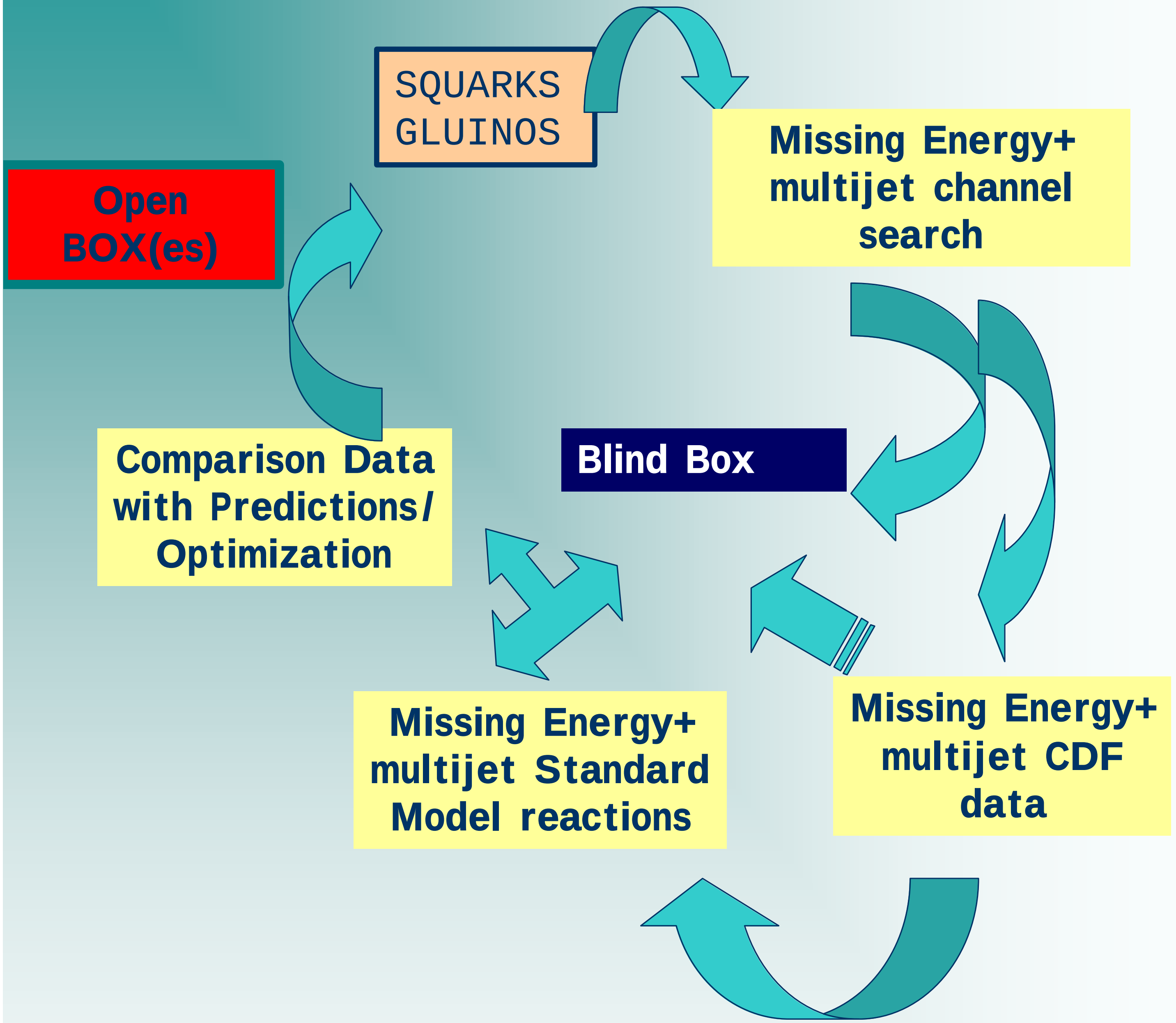
Diboson

QCD multijet

E
W
K

Note: The missing energy **is** a QCD sample

SEARCH OUTLINE



SQUARKS
GLUINOS

SUPERSYMMETRY Fermion❖Boson

Solves the "hierarchy problem"

Apparently Unifies the three gauge couplings

$R=(-1)^{3(B-L)+2S}$ +1 (SM particles)
-1 SUSY particles

If R-parity is conserved
- sparticles are produced in pairs and eventually decay to the Lightest SUSY Particle (LSP)
- the LSP is stable and weakly interacting
> missing energy signature

LSP is a good candidate for dark matter

Name	Spin	R	Mass Eigenstates	Gauge Eigenstates
Higgs bosons	0	$+1$	$h^0\ H^0\ A^0\ H^\pm$	$H_u^0\ H_d^0\ H_u^+\ H_d^-$
squarks	0	-1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$
sleptons	0	-1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$
neutralinos	1/2	-1	M1 $\tilde{\chi}_1^0\ \tilde{\chi}_2^0\ \tilde{\chi}_3^0\ \tilde{\chi}_4^0$	$\tilde{B}^0\ \widetilde{W}^0\ \widetilde{H}_u^0\ \widetilde{H}_d^0$
charginos	1/2	-1	M2 $\tilde{\chi}_1^\pm\ \tilde{\chi}_2^\pm\ \tilde{\chi}_3^\pm$	$\widetilde{W}^\pm\ \widetilde{H}_u^+\ \widetilde{H}_d^-$
gluino	1/2	-1	M3 $\tilde{g}$	$\tilde{g}$
gravitino/ goldstino	3/2	-1	$\tilde{G}$	$\tilde{G}$

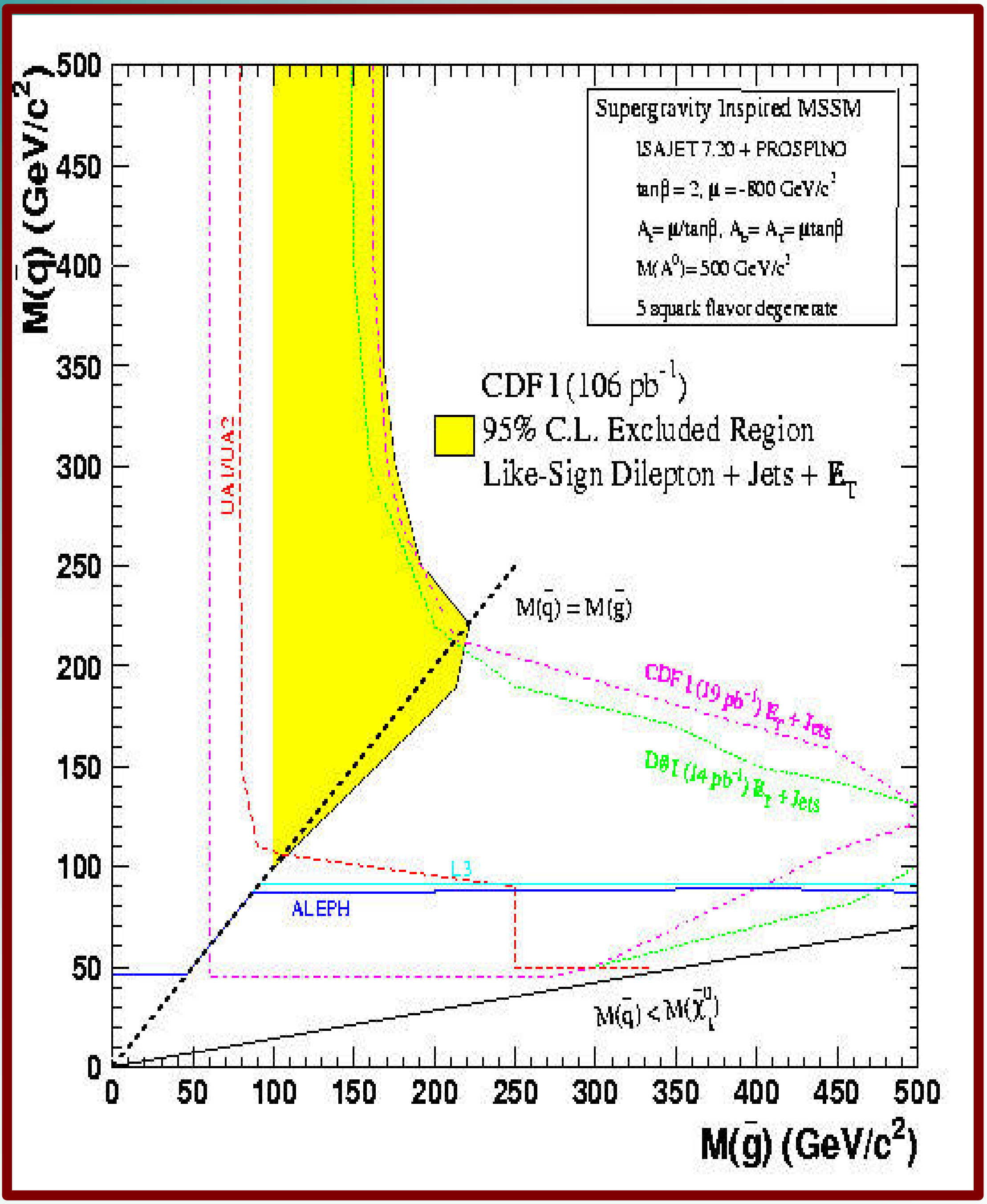
The Super-Models

MSSM

$m_{\tilde{g}}$	gluino mass
μ	Higgs mass parameter
$\tan\beta$	$\frac{\upsilon_2}{\upsilon_1}$
A	mass of CP-odd Higgs
$m_{\tilde{l}}, m_{\tilde{q}}$	slepton and squark masses
$A_{\tilde{l}}, A_{\tilde{q}}$	trilinear couplings

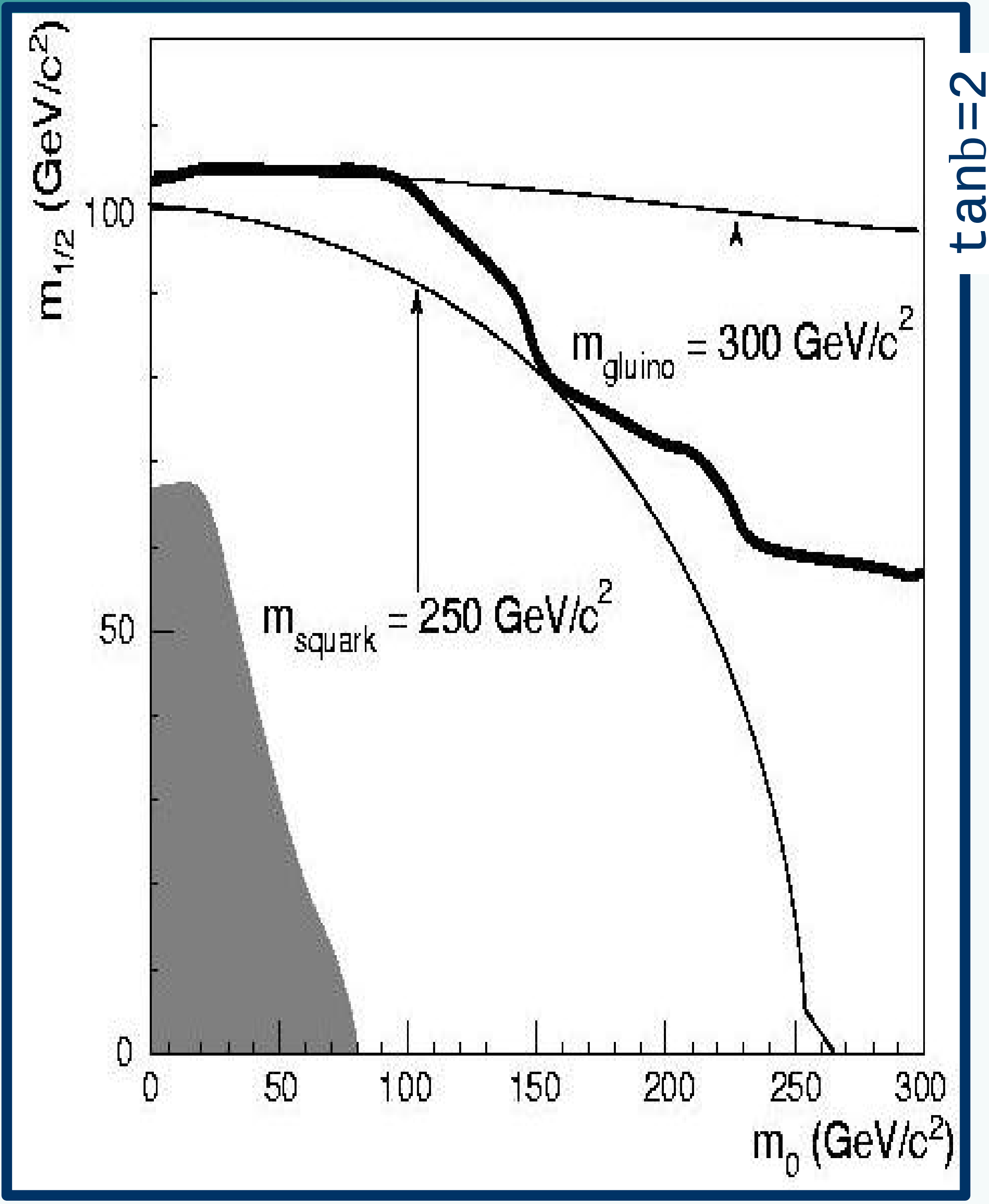
mSUGRA

$M_{1/2}$	unified gaugino masses
M_0	unified scalar masses
$\tan\beta$	$\frac{\upsilon_2}{\upsilon_1}$
A_0	unified trilinear couplings
sign μ	

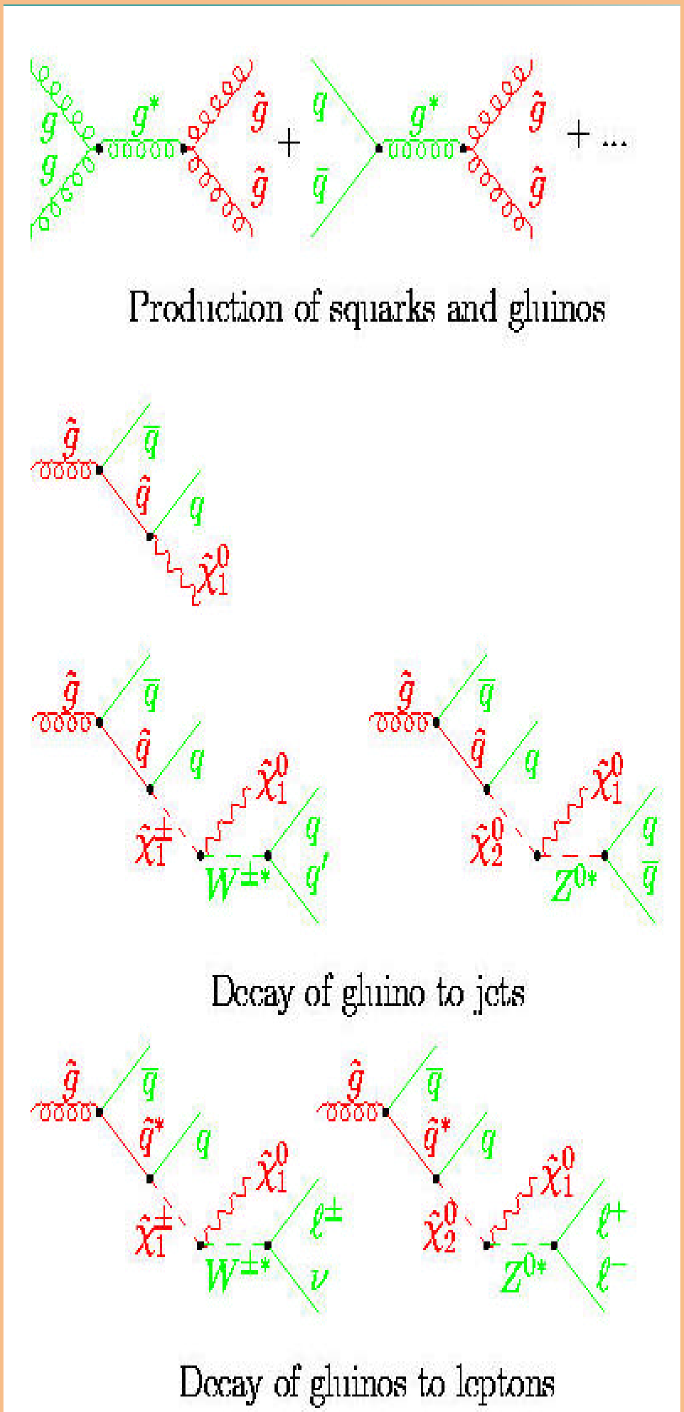


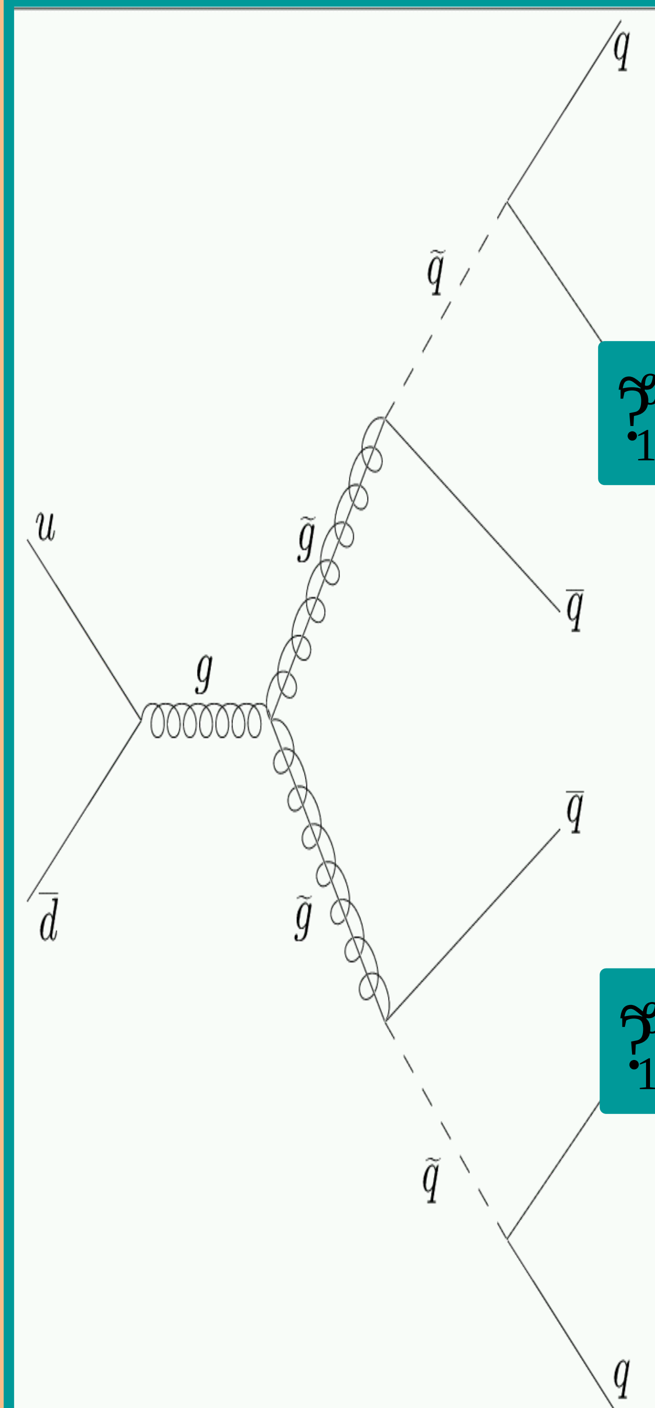
Present Results

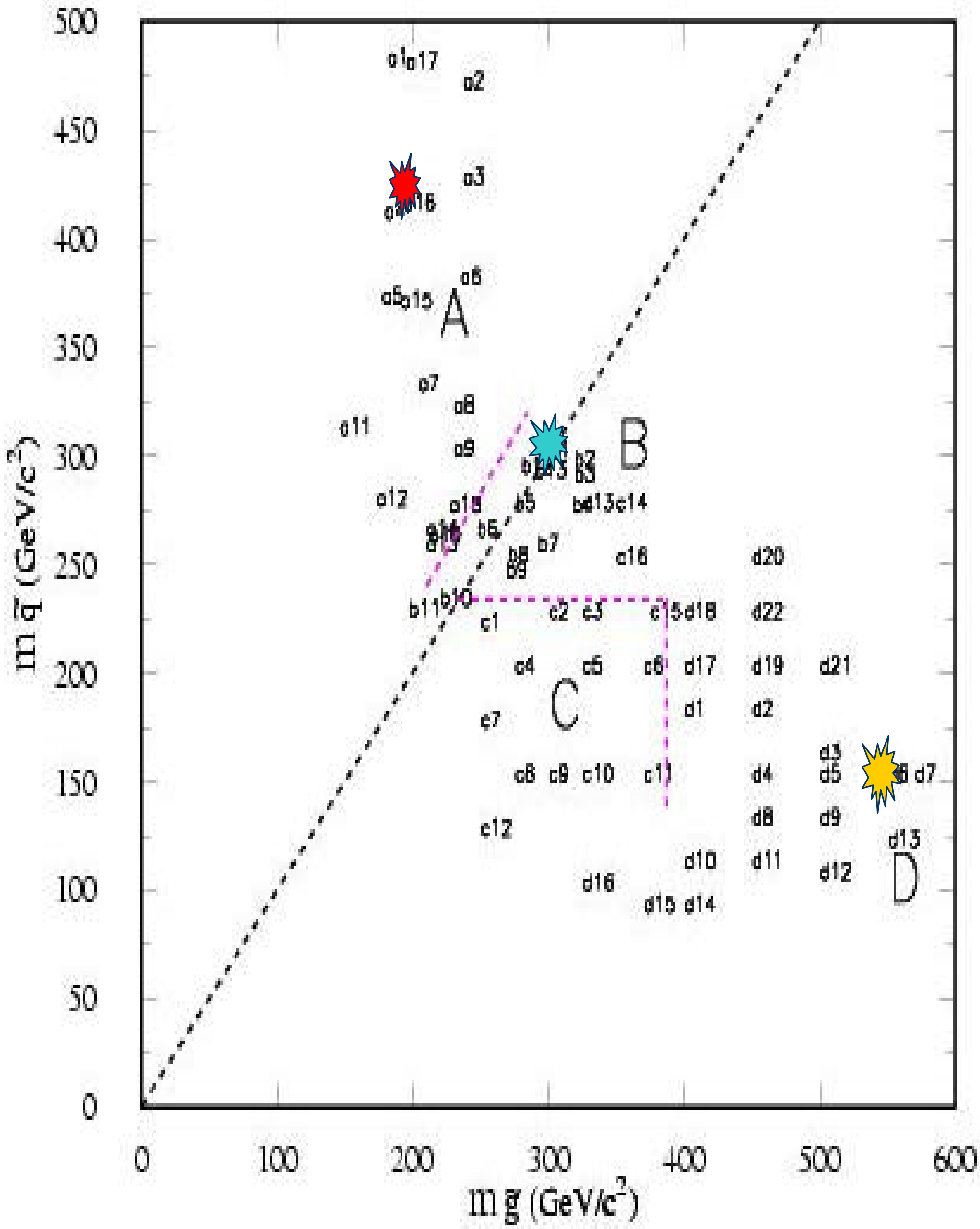
mSUGRA DØ result

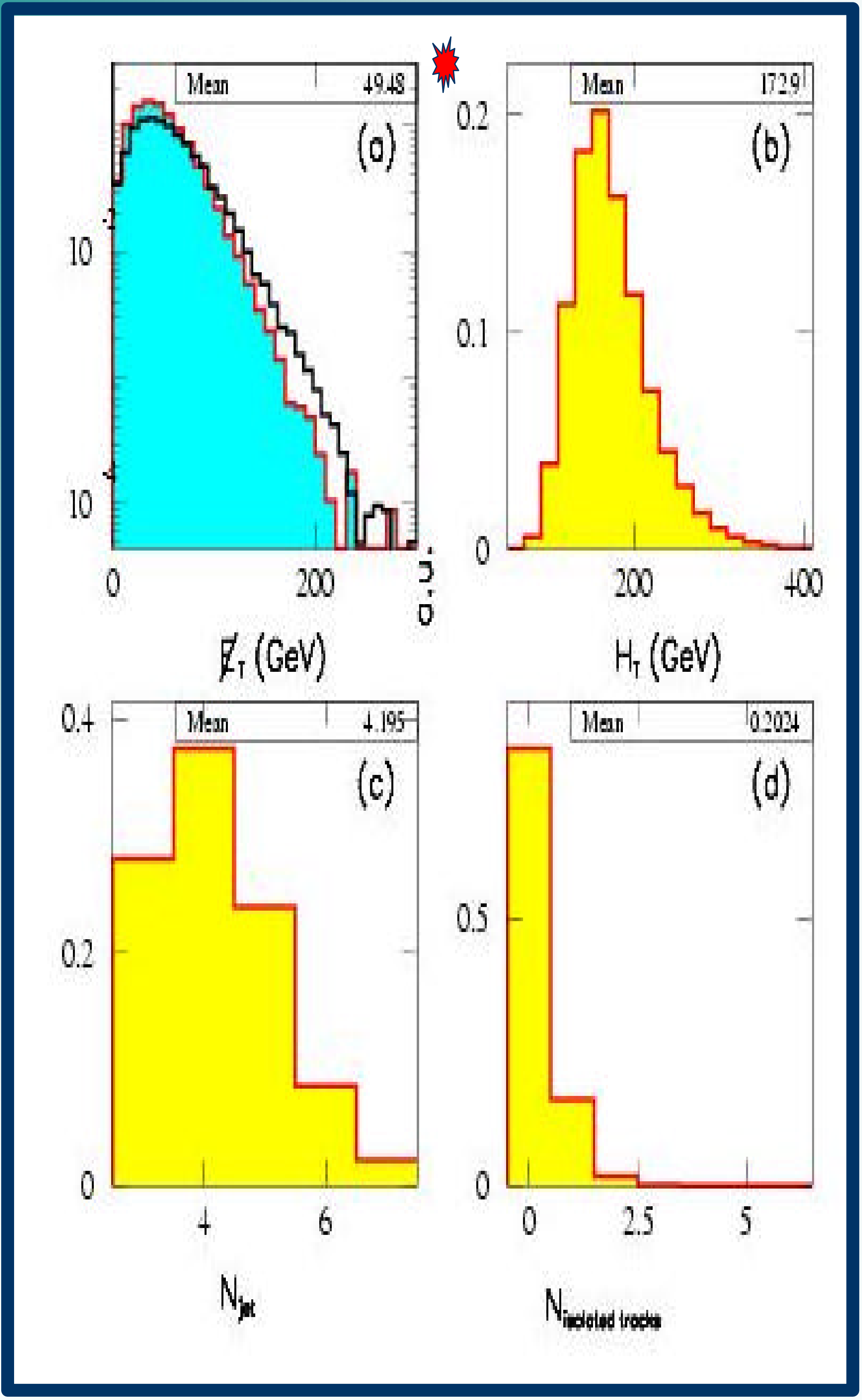


Production/Decay Graphs

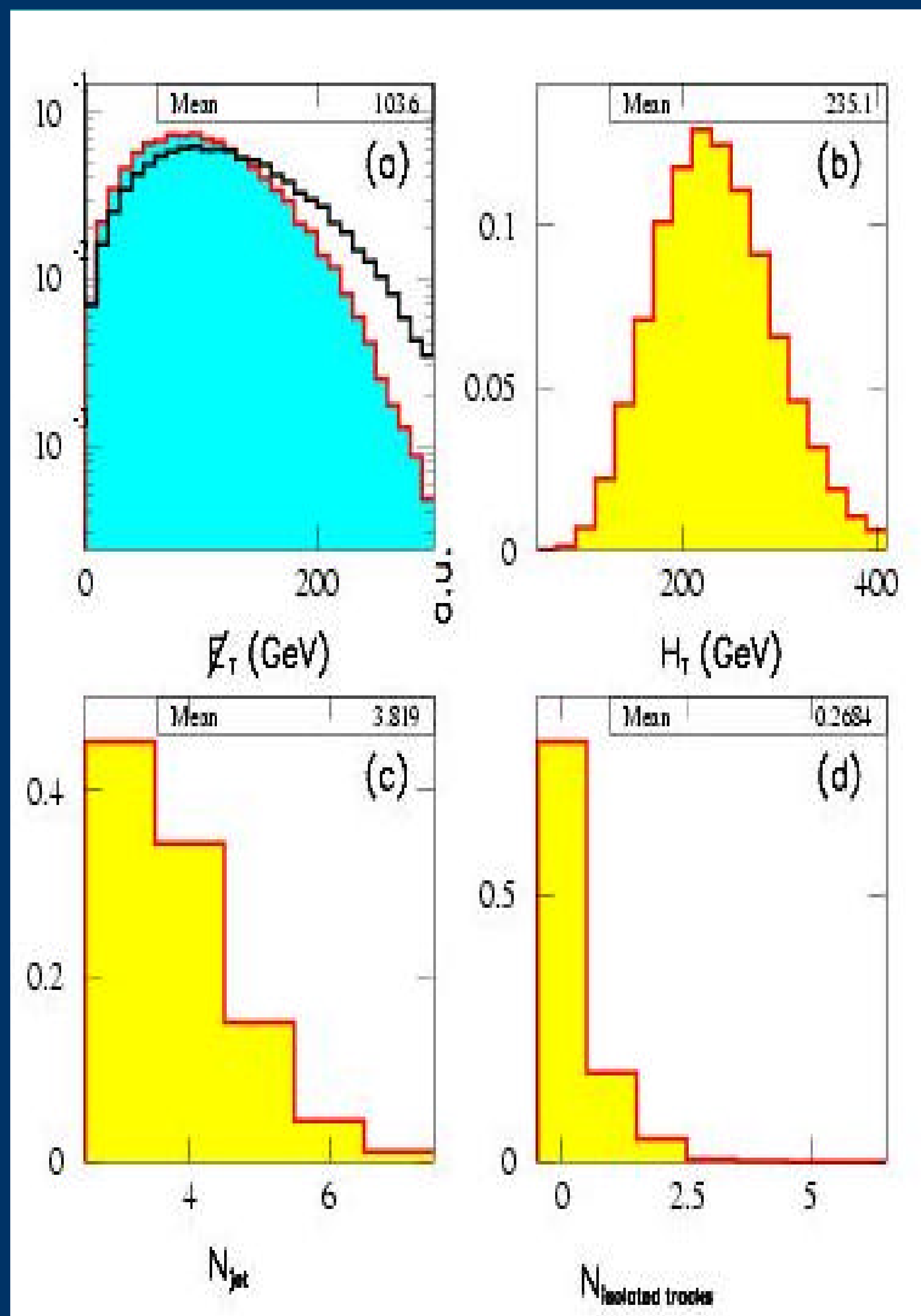




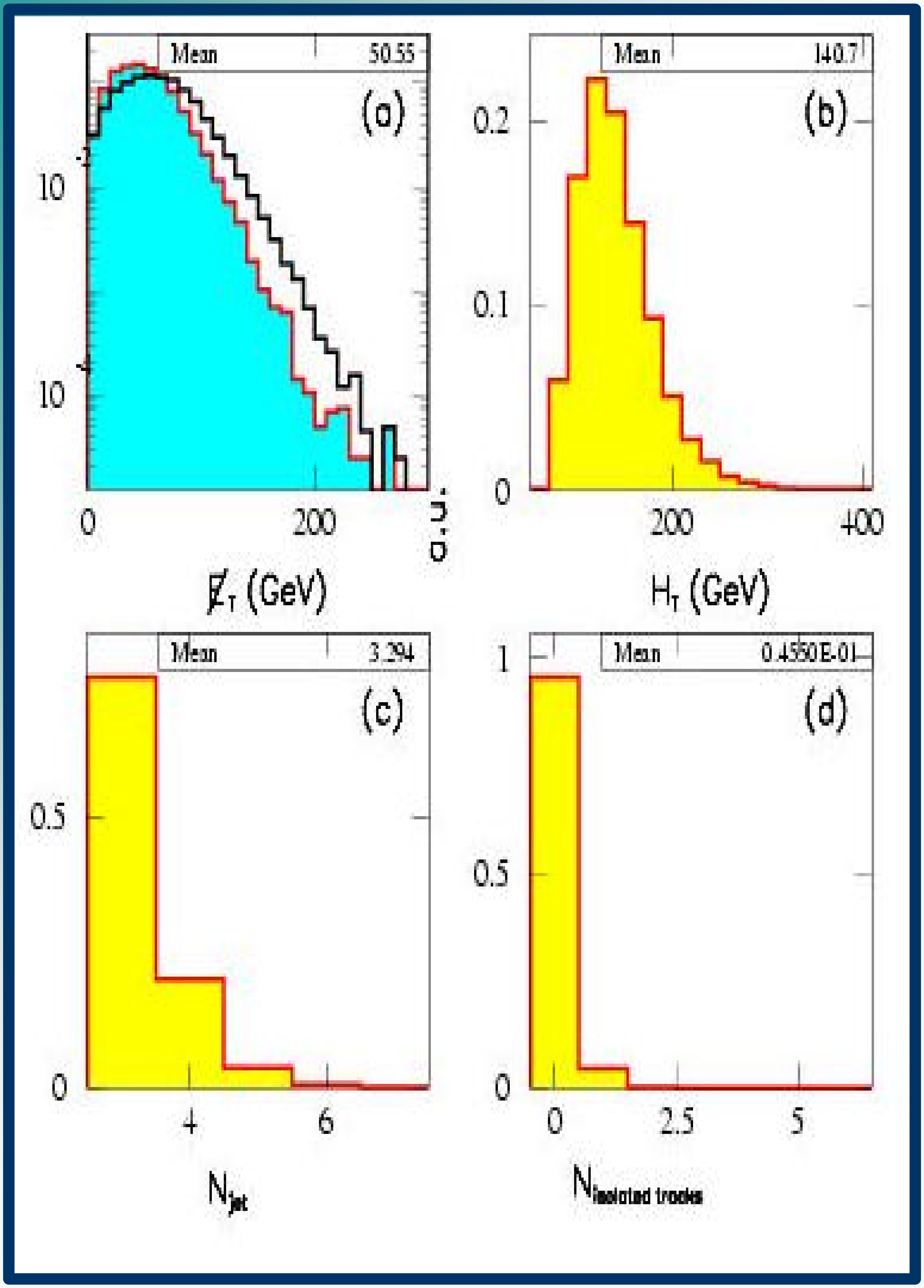

m q̃ (GeV/c²)
m g̃ (GeV/c²)
A
B
C
D



Mean 49.48
(a)
10
10
0
200
a.u.
$\not{E}_T$ (GeV)
Mean 172.9
(b)
0.2
0.1
0
200
400
H_T (GeV)
Mean 4.195
(c)
0.4
0.2
0
4
6
N_{jet}
Mean 0.2024
(d)
0.5
0
0
2.5
5
$N_{isolated\ tracks}$



Mean 103.6
(a)
10
10
10
0
200
a.u.
$\not{E}_T$ (GeV)
Mean 235.1
(b)
0.1
0.05
0
200
400
H_T (GeV)
Mean 3.819
(c)
0.4
0.2
0
4
6
N_{jet}
Mean 0.2684
(d)
0.5
0
0
2.5
5
$N_{isolated\ tracks}$



Mean 50.55
(a)
10
10
0
200
E̸T (GeV)
a.u.
Mean 140.7
(b)
0.2
0.1
0
200
400
HT (GeV)
Mean 3.294
(c)
0.5
0
4
6
Njet
Mean 0.4550E-01
(d)
1
0.5
0
0
2.5
5
Nisolated tracks

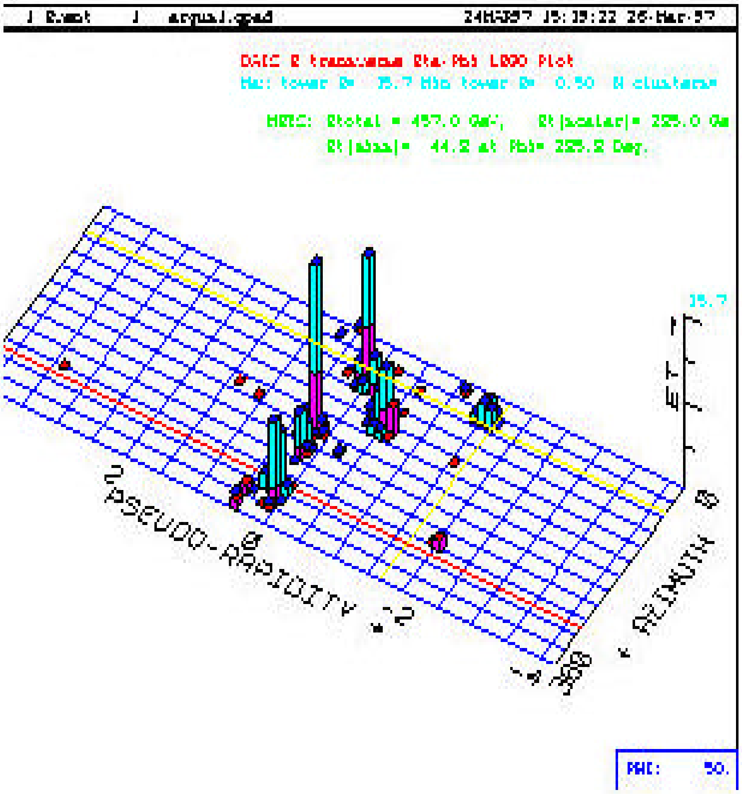
ANALYSIS DRIVING VARIABLES

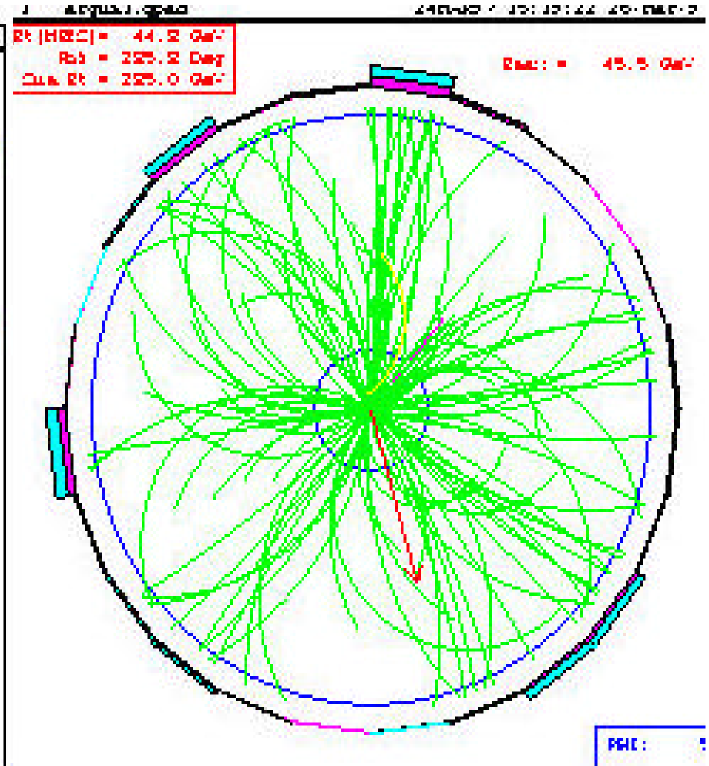
The Missing Transverse Energy $\not{E}_T$

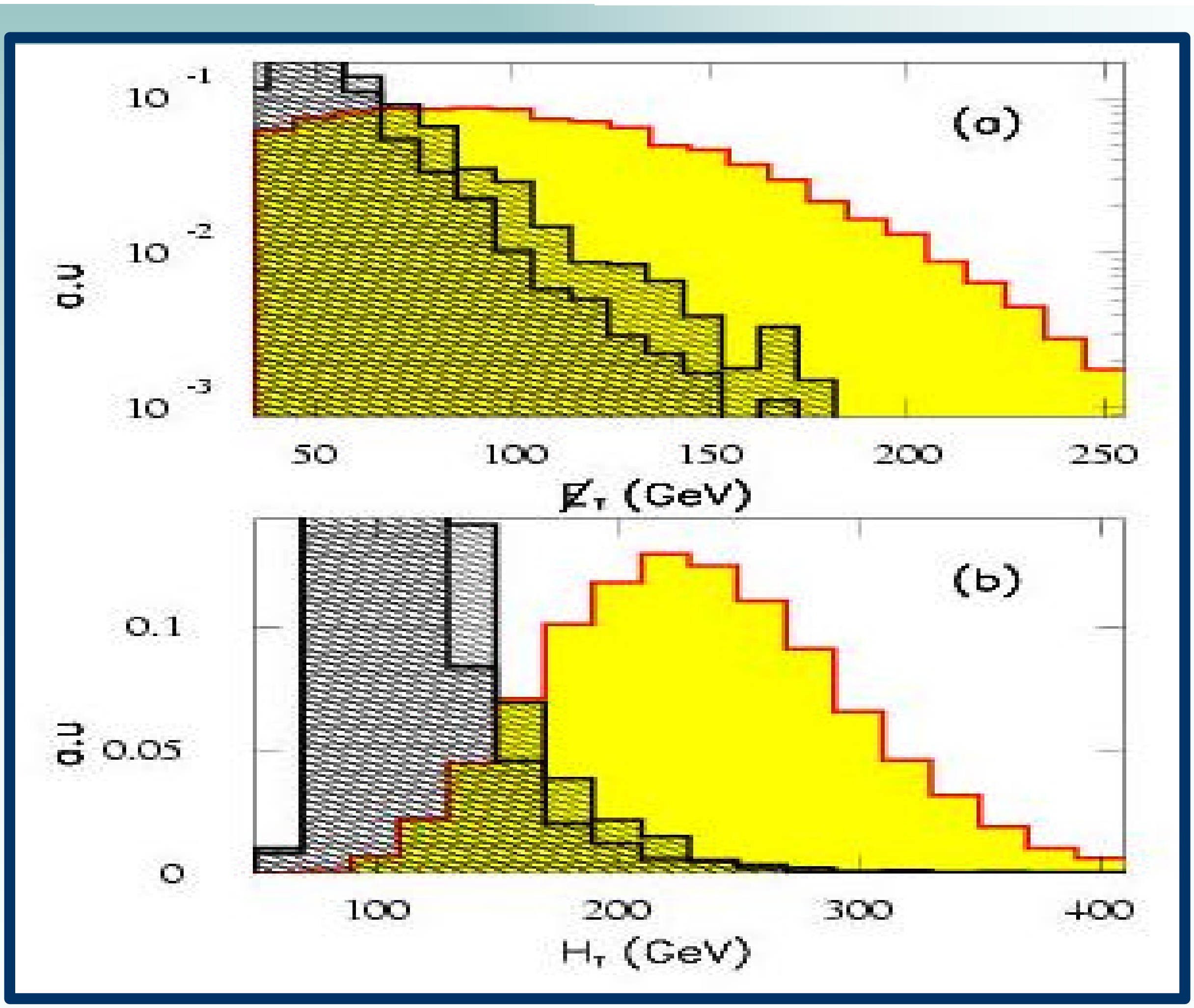
The Number of Jets N_{jet}

$$E_T(2^{ndjet}) + E_T(3^{rdjet}) + \not{E}_T \quad H_T$$

The Number of isolated tracks N_{trk}^{iso}

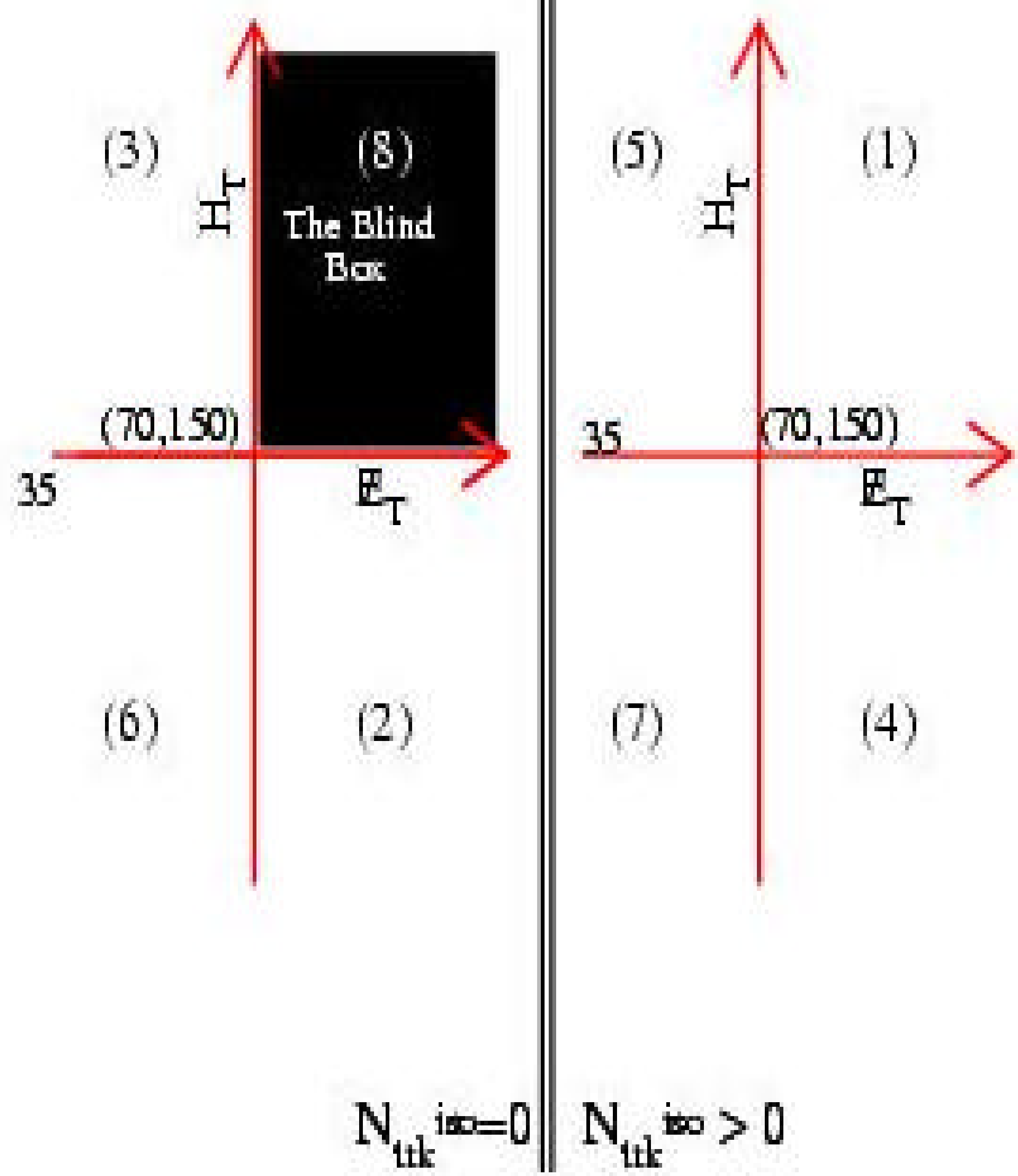






(a)
a.u
$\not\!E_T$ (GeV)
(b)
a.u
H_T (GeV)

“The BOX”


(3)
(8)
The Blind Box
(5)
(1)
H_T
H_T
(70,150)
35
E_T
(70,150)
35
E_T
(6)
(2)
(7)
(4)
$N_{trk}^{iso}=0$
$N_{trk}^{iso}>0$

$Z/W + \geq N$ jets(N=2,3)

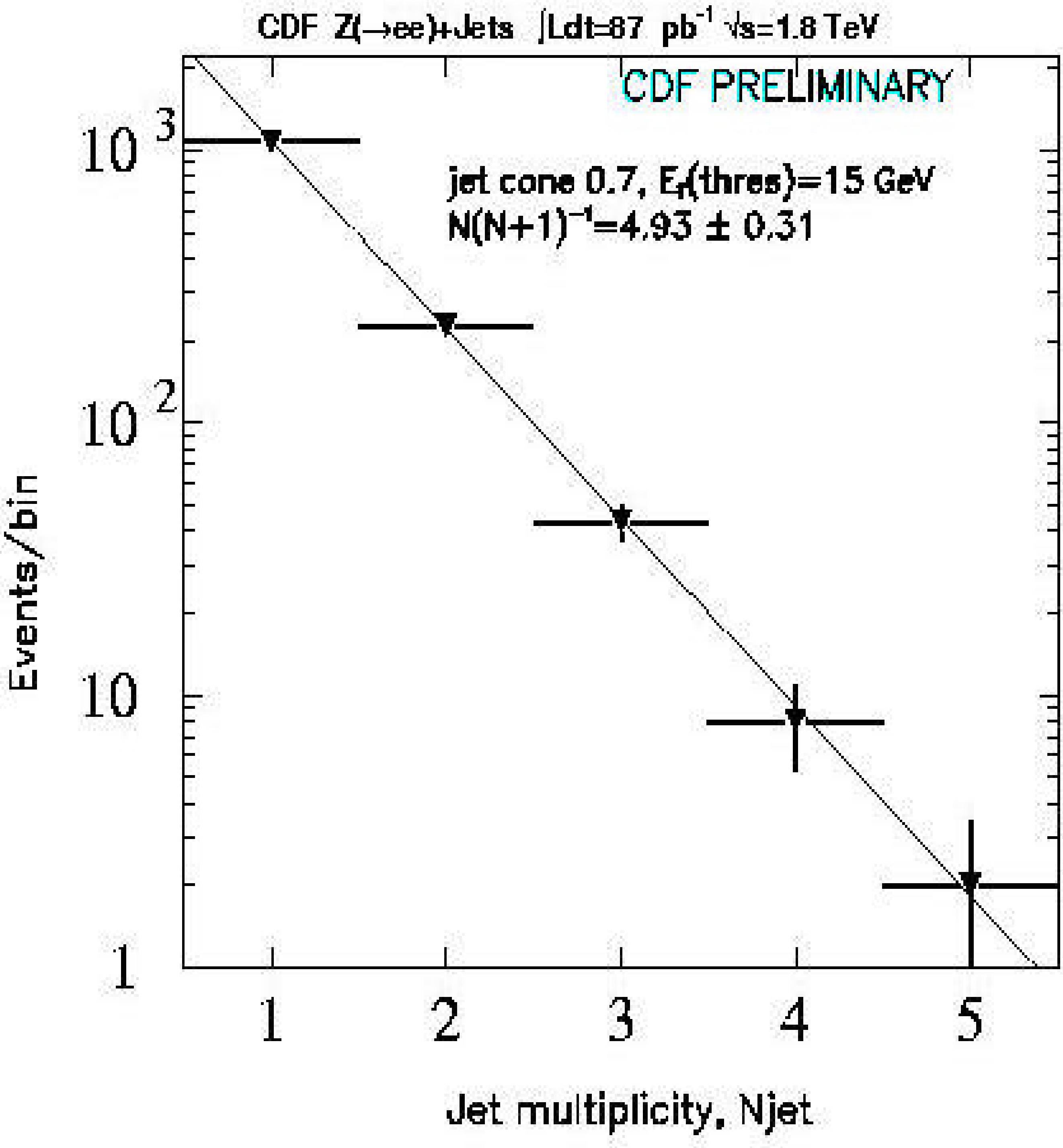
For this analysis the Z/W + N jet predictions are normalized to the Zee+jets CDF data using:

$$R = \left.\frac{N}{N+1}\right|^{DATA}$$ to normalize the 3 jet predictions using the 2 jet data

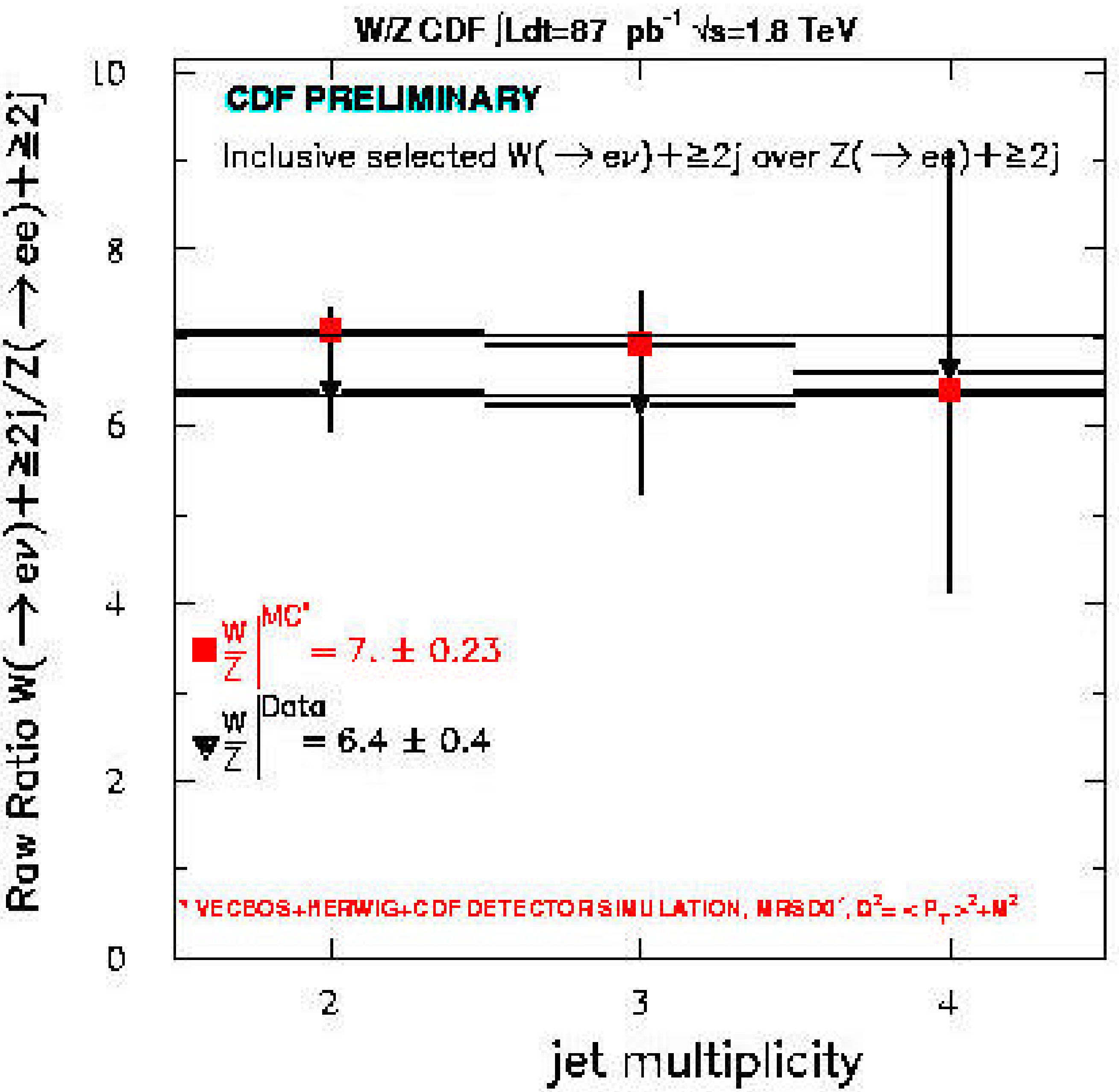
$$R' = \left.\frac{W}{Z}\right|^{MC}$$ to normalize the W predictions using the Z data

Ratios in the normalization:

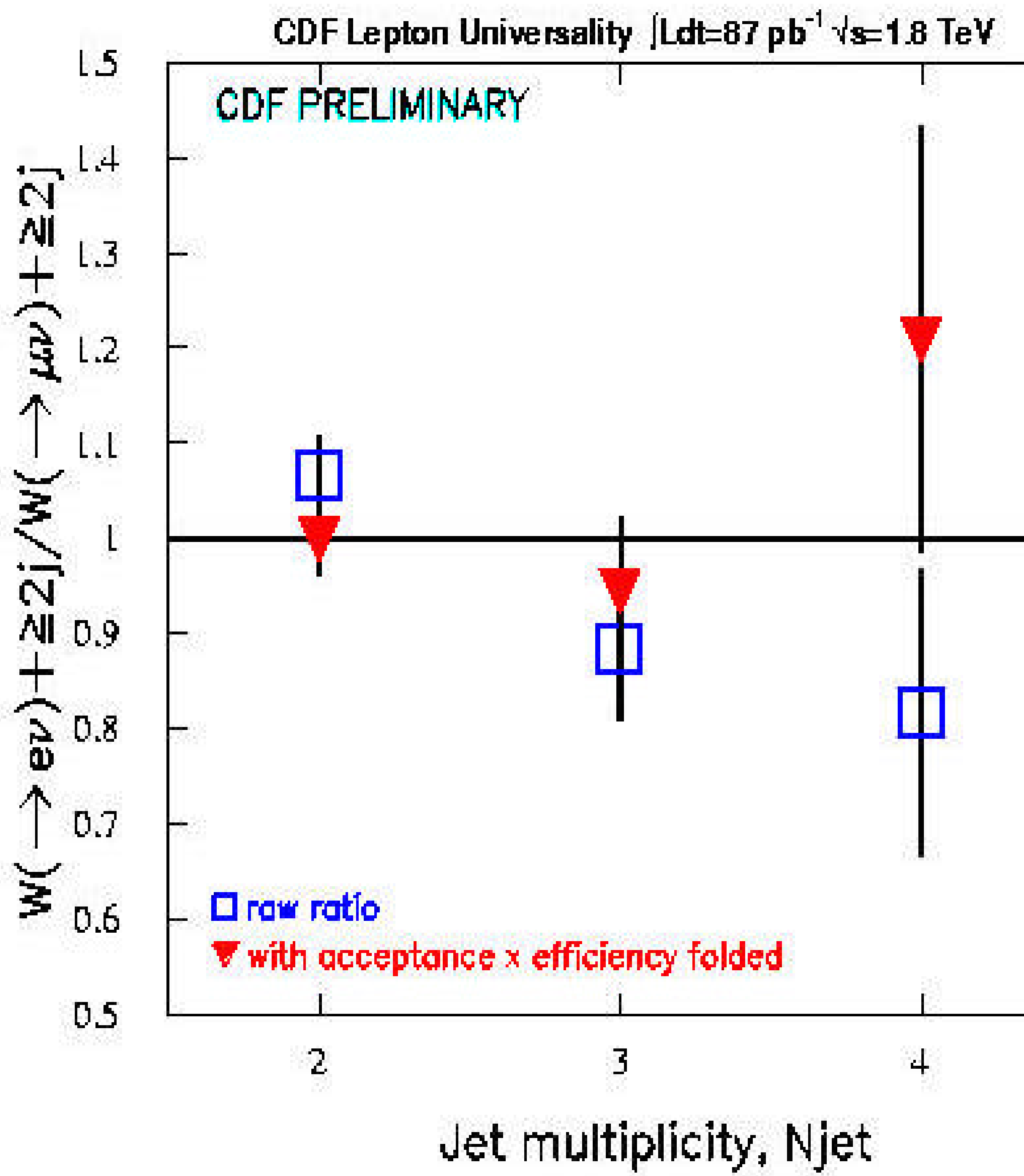
Ldσ/dNjet



Ratios in the normalization: $\frac{W}{Z}$

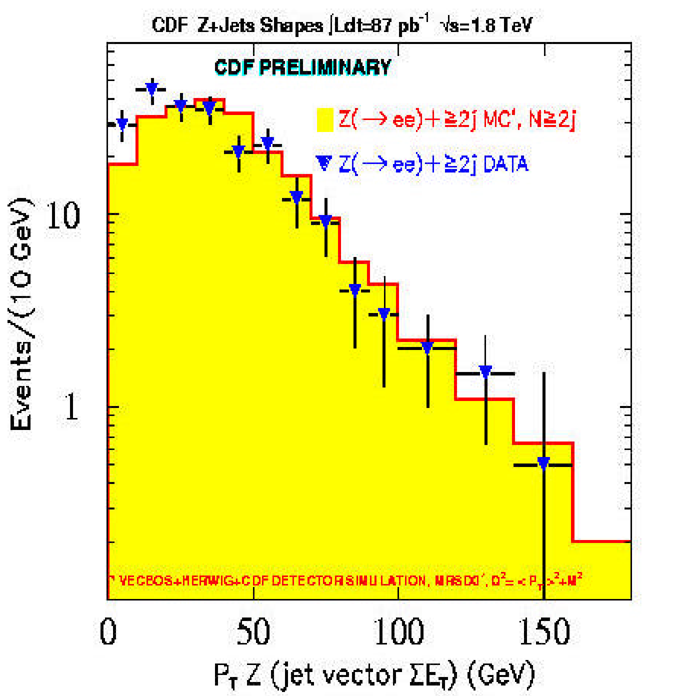


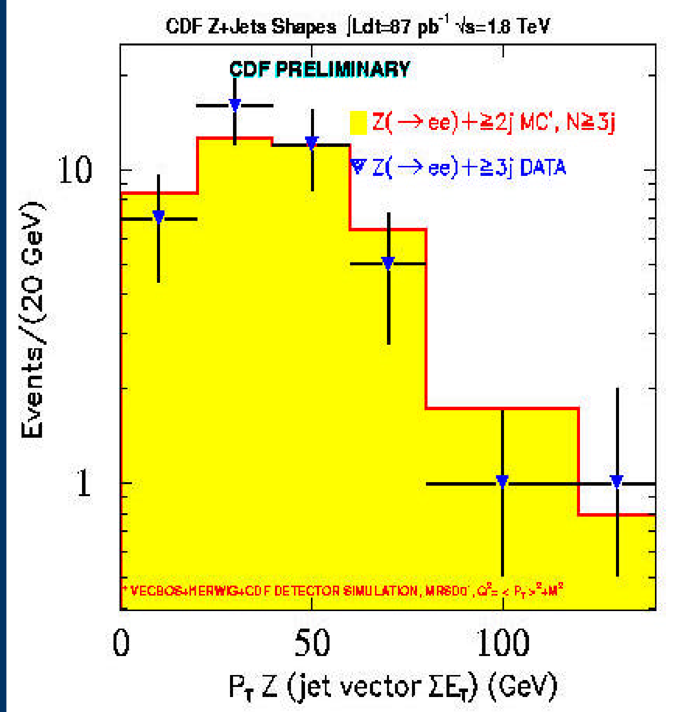
Lepton Universality

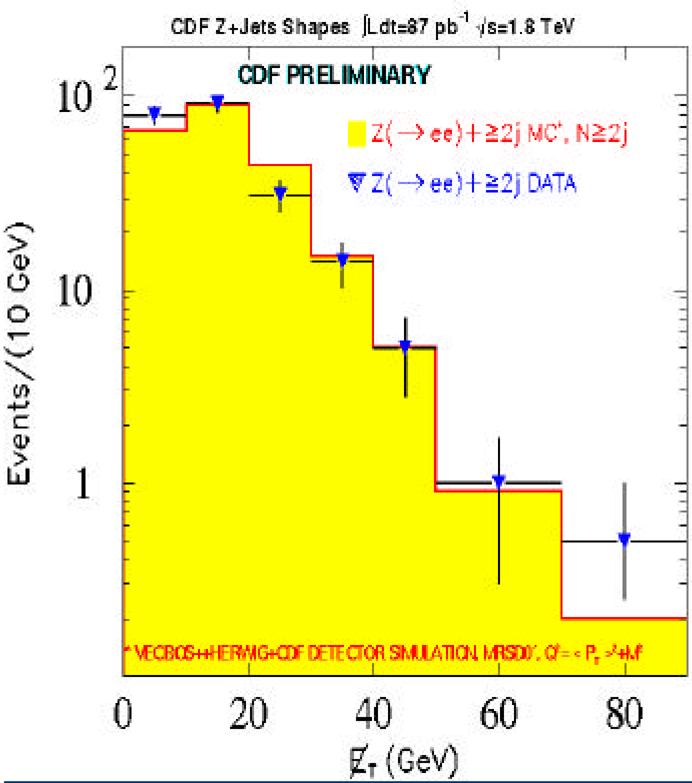


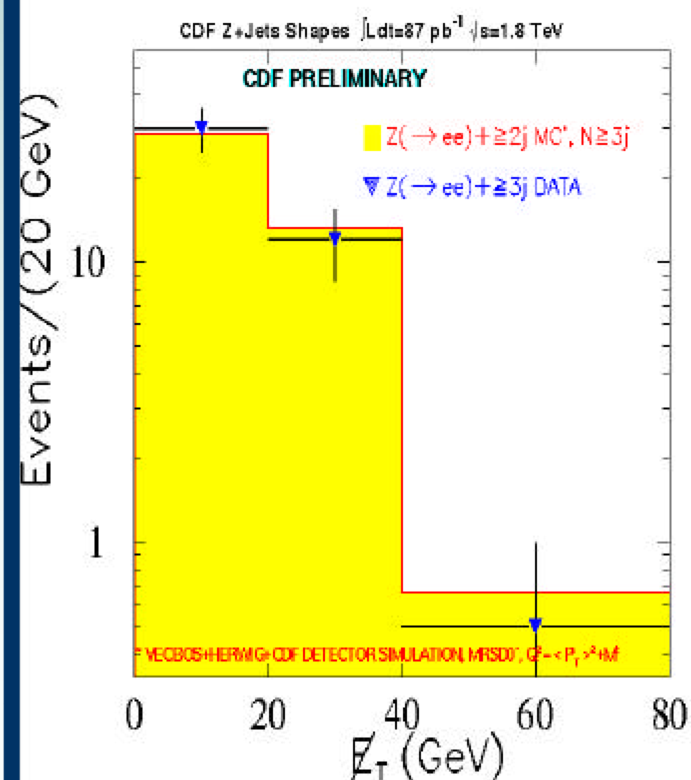
Z+ ≥ N jets(N=2,3)

SHAPES



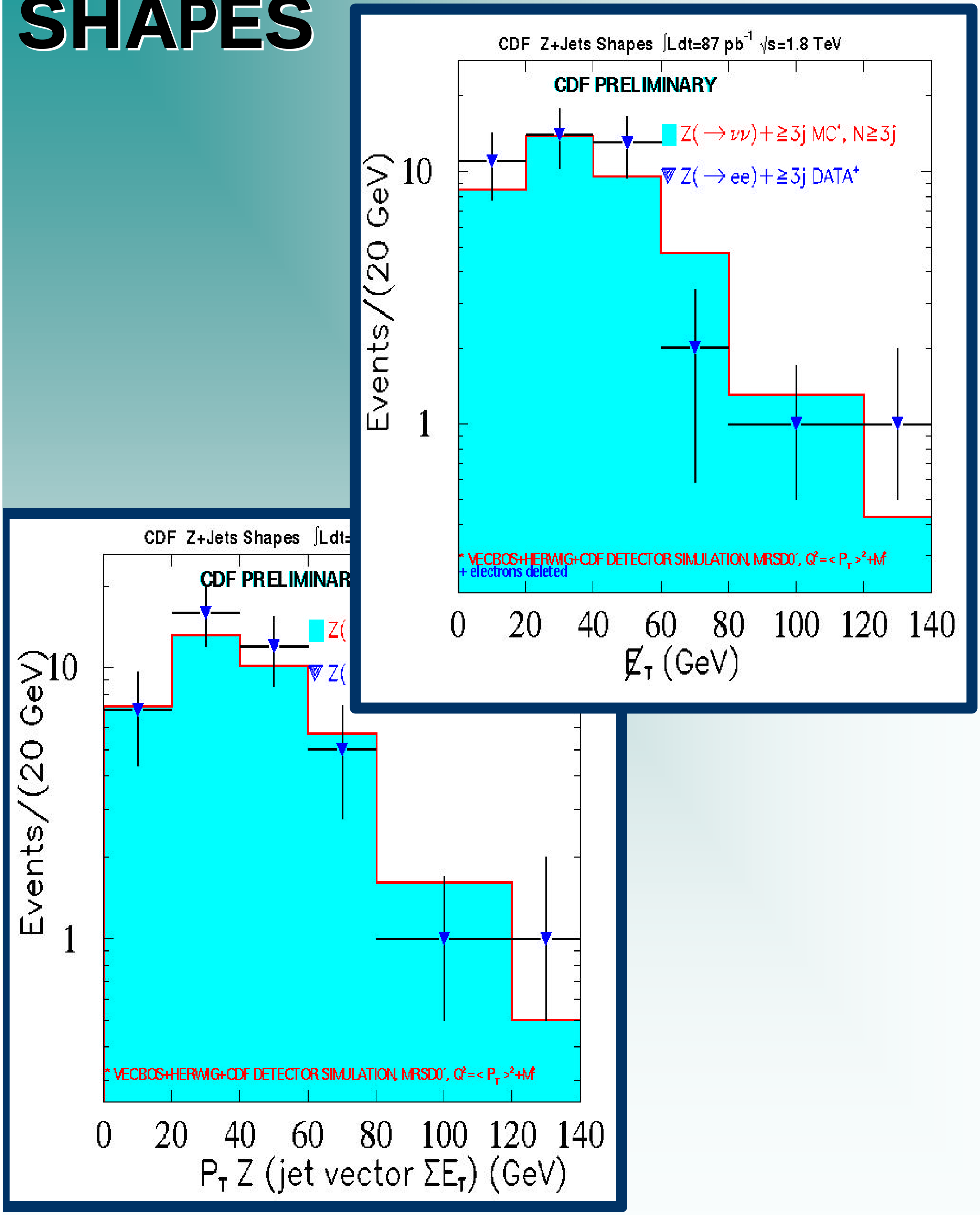






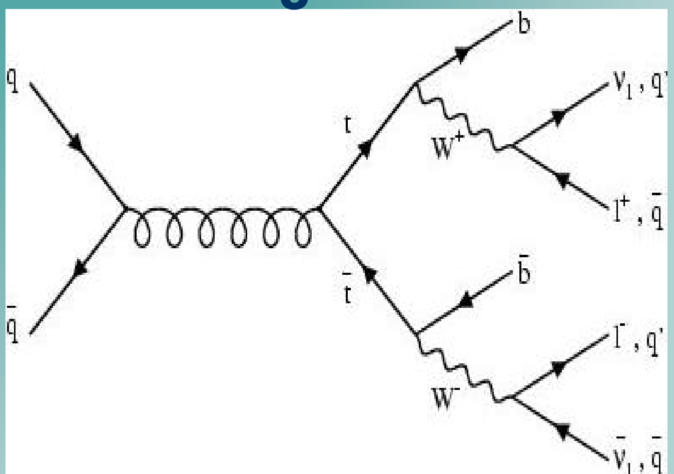
Z+ ≥ N jets(N=2,3)

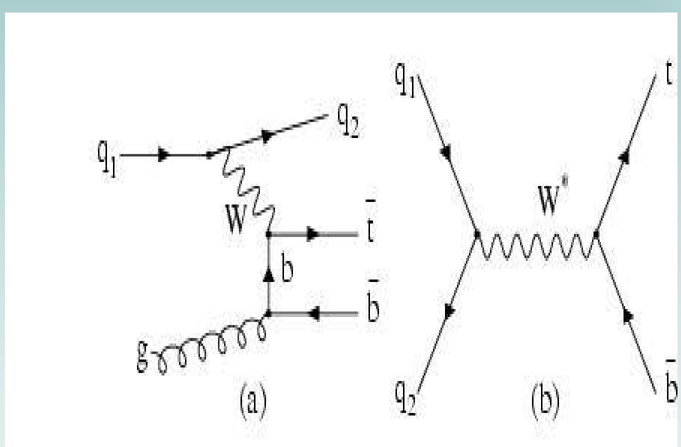
SHAPES

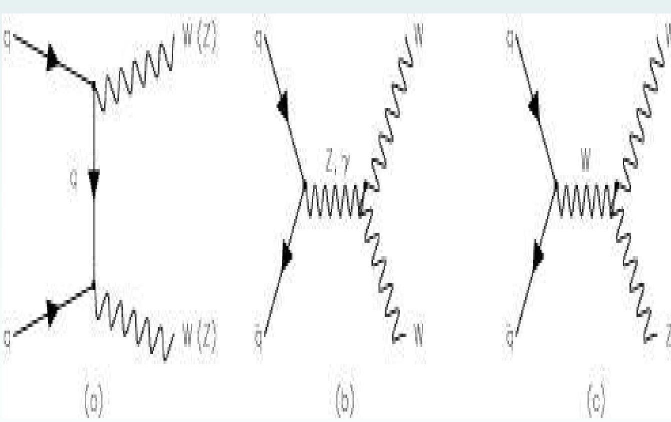


$t\bar{t}$, singletop,diboso

MC samples Luminosity norm using theoretical cross sections







$\sigma_{t\bar{t}} = 5.06\ \mathrm{pb} \pm 18\%$

$\sigma_{Wg} = 1.7\ \mathrm{pb} \pm 17\%,$

$\sigma_{W^* \to t\bar{b}} = 0.73\ \mathrm{pb} \pm 9\%$

$\sigma_{WW} = 9.5\ \mathrm{pb} \pm 7\%$

$\sigma_{WZ} = 2.6\ \mathrm{pb} \pm 12\%$

$\sigma_{ZZ} = 1.\mathrm{pb} \pm 20\%$

QCD MULTIJET BACKGROUND

➢ Simulate 3-jet events for a very low threshold trigger (JET20) and a higher threshold trigger (JET50).

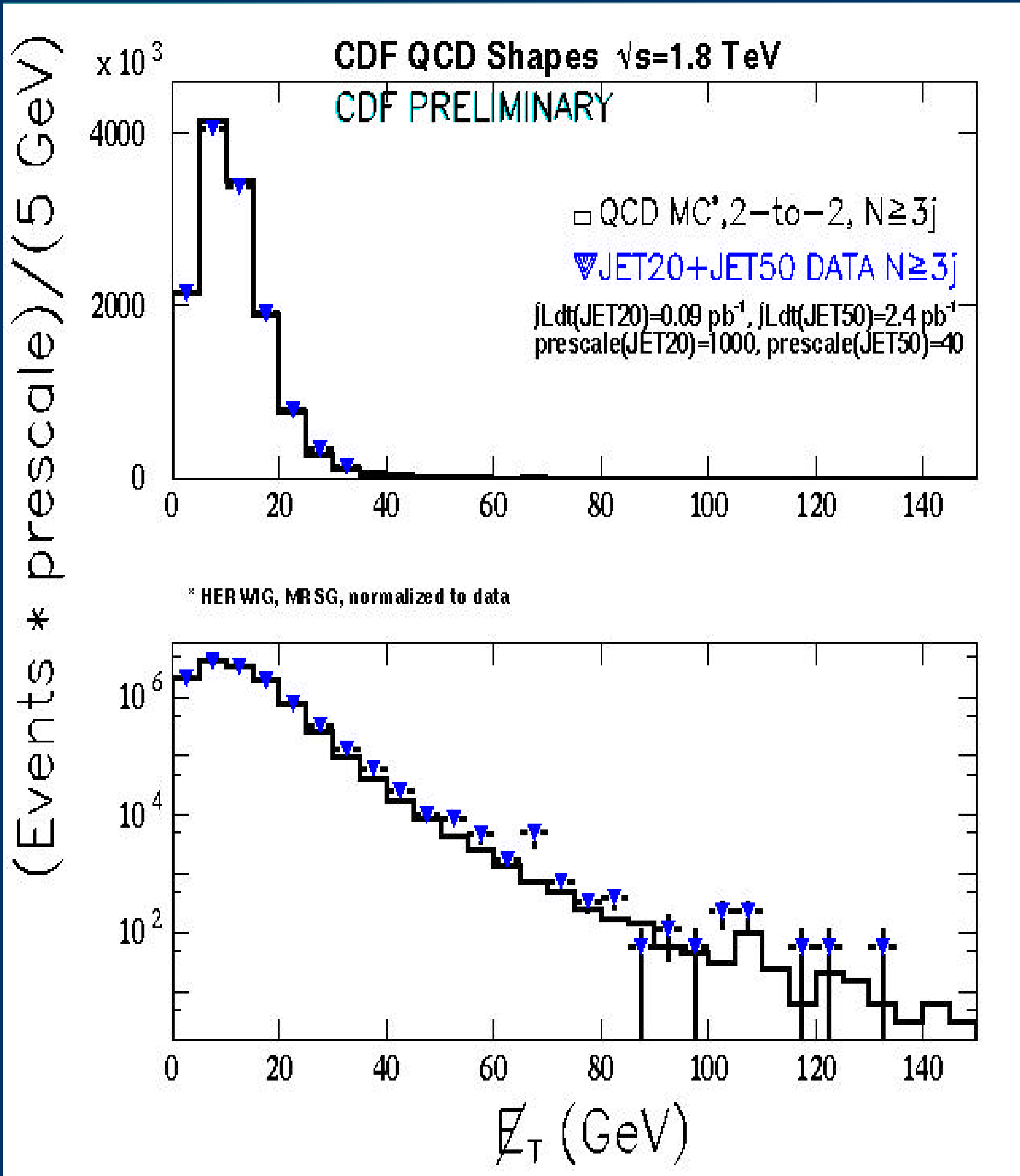
➢ NO Missing Energy required- use the whole Missing Energy spectrum.

➢ Fold in the trigger efficiencies measured in the data.

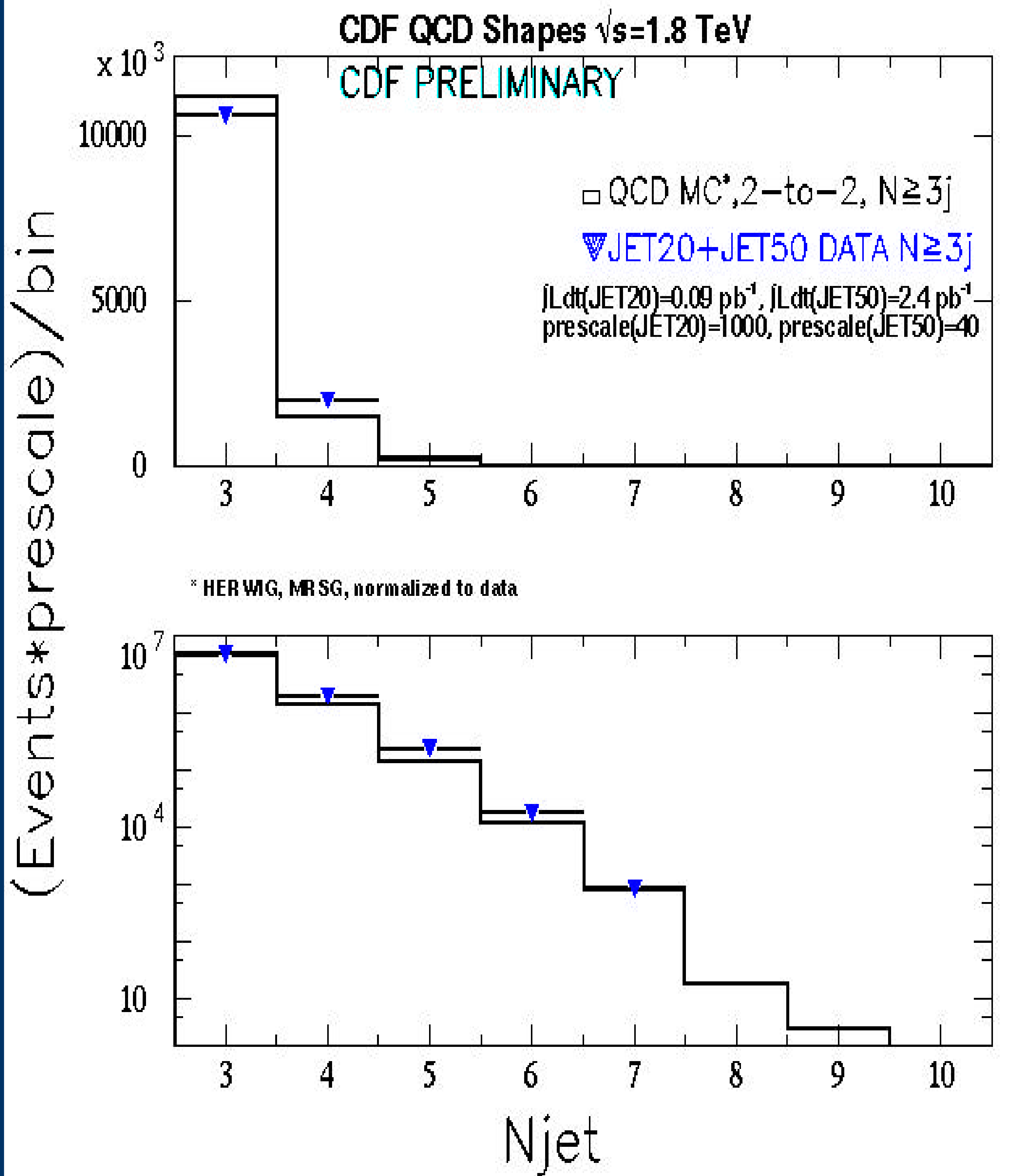
➢ Merge samples and compare kinematic lineshapes between data and QCD predictions.

➢ Measure the prescale factors and Luminosity of the JET data samples used.

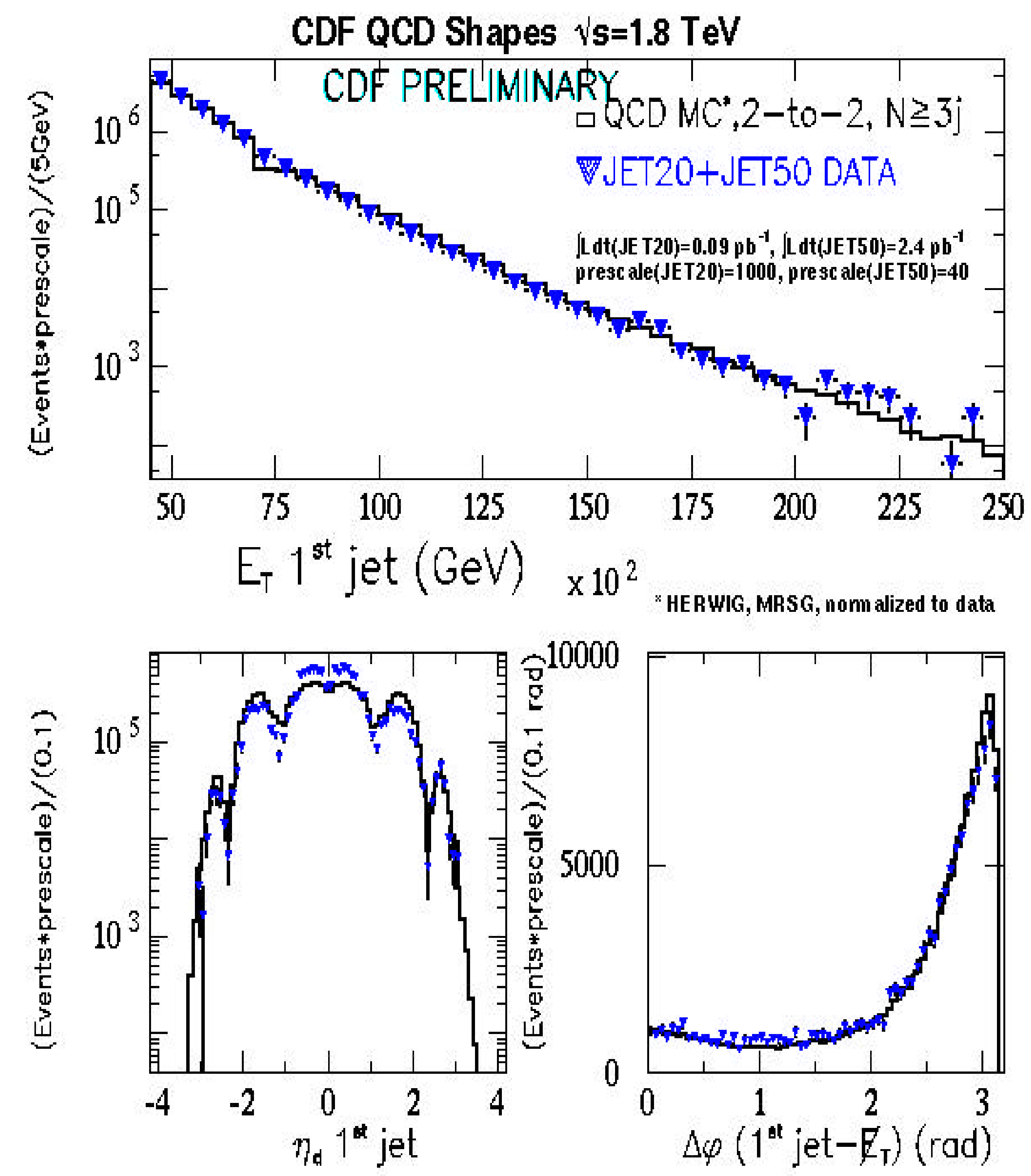
QCD MULTIJET BACKGROUND



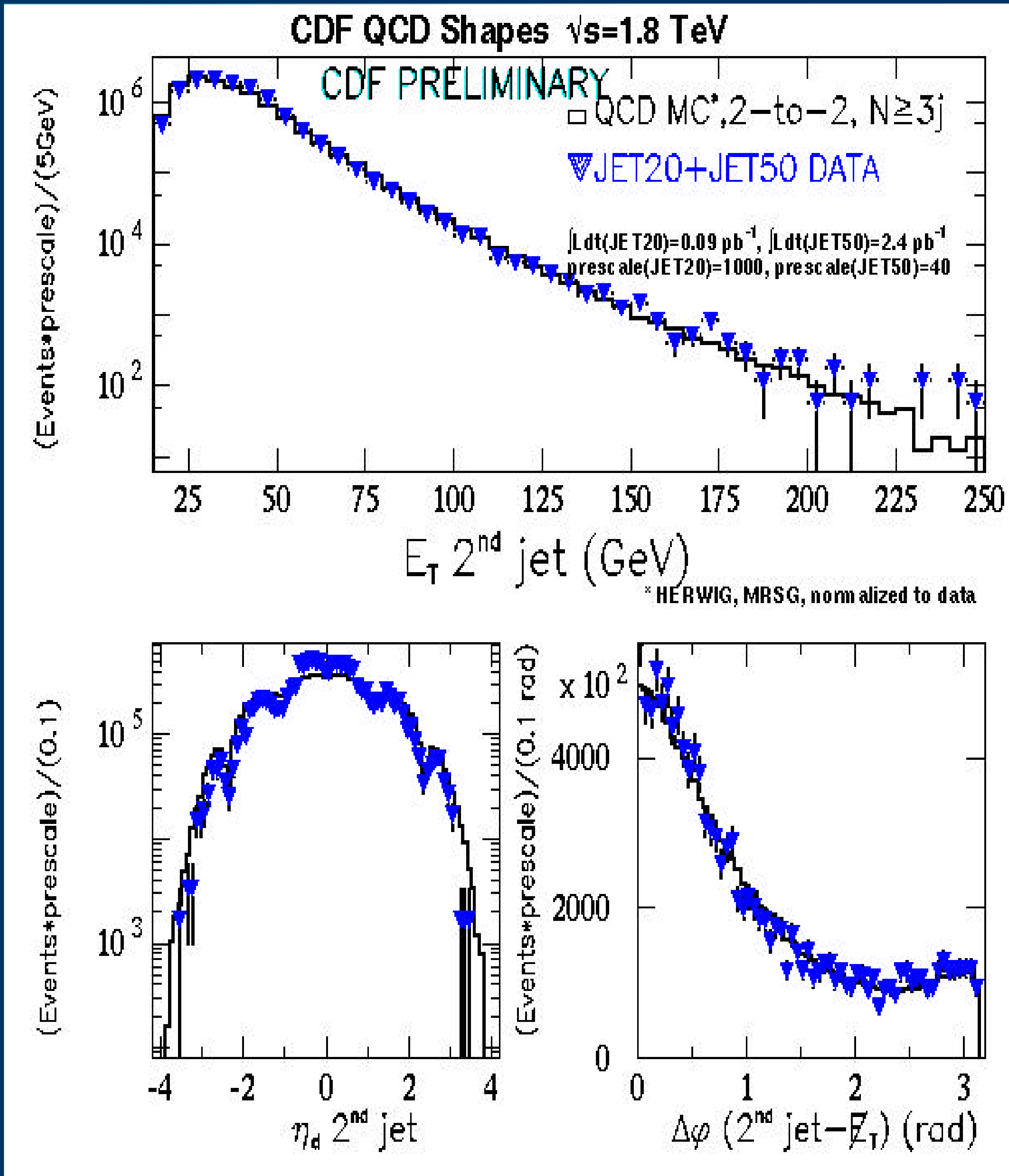
QCD MULTIJET BACKGROUND



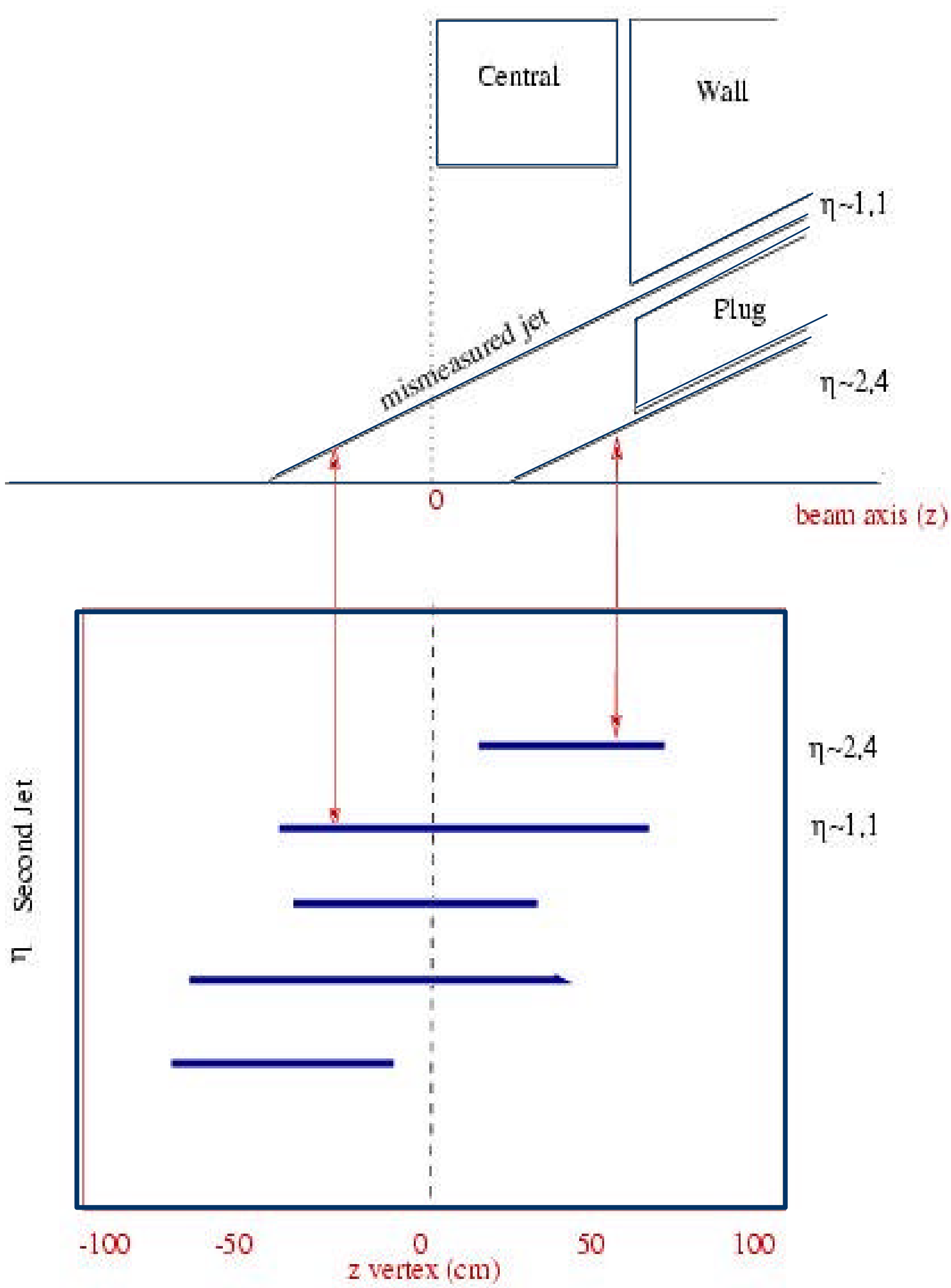
QCD MULTIJET BACKGROUND



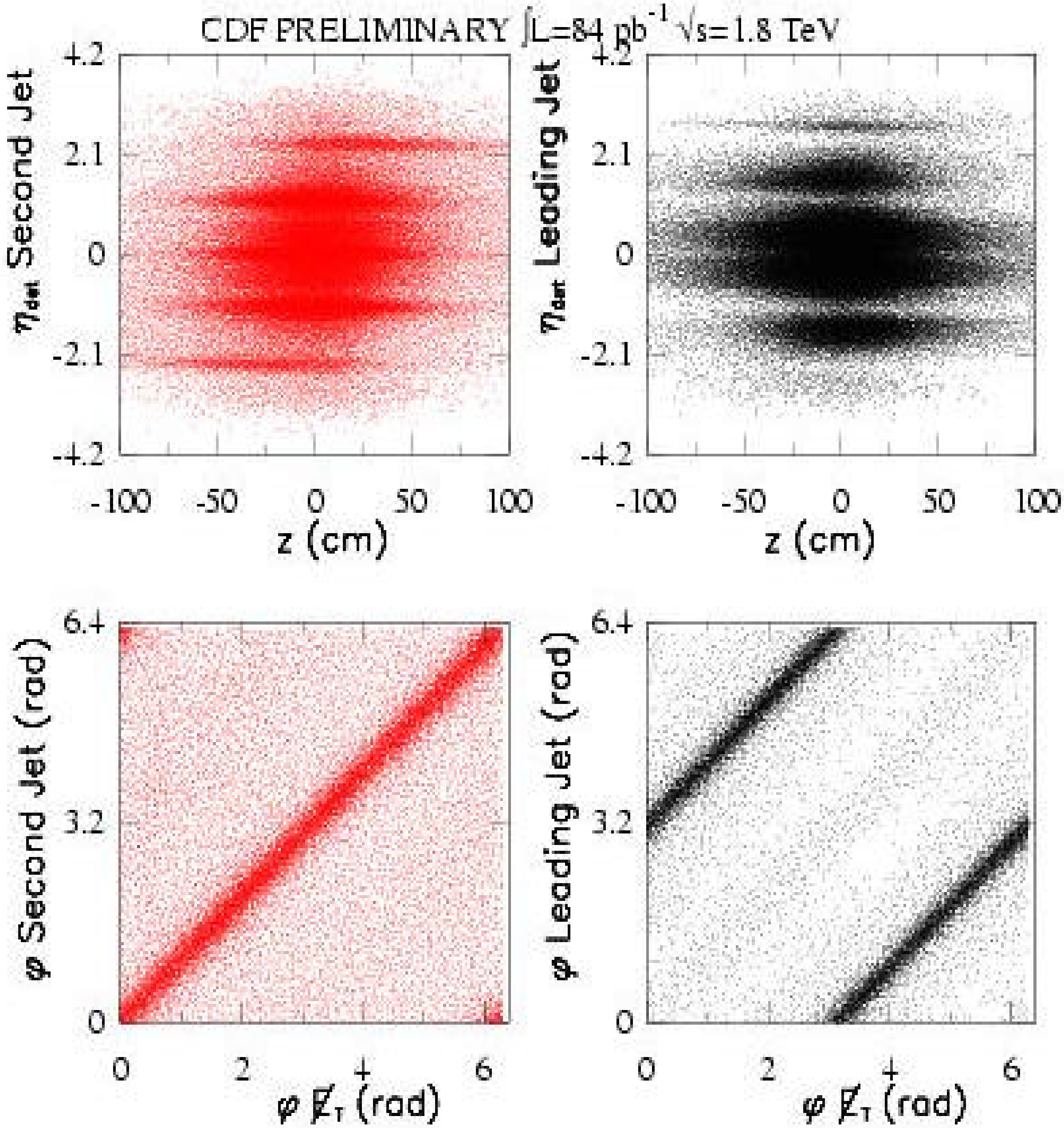
QCD MULTIJET BACKGROUND



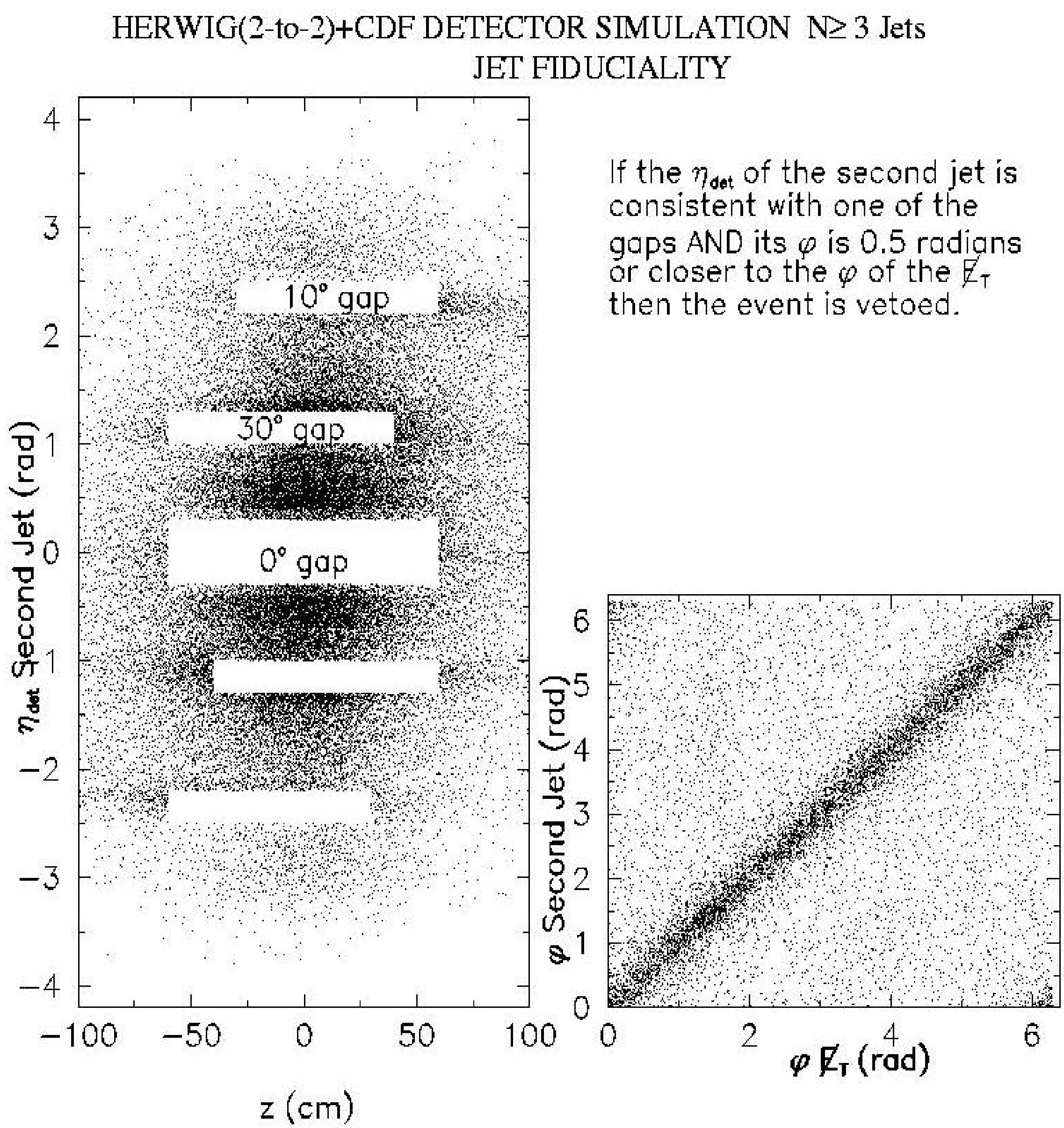
Missing Energy from QCD mismeasurements



Missing Energy from QCD mismeasurements



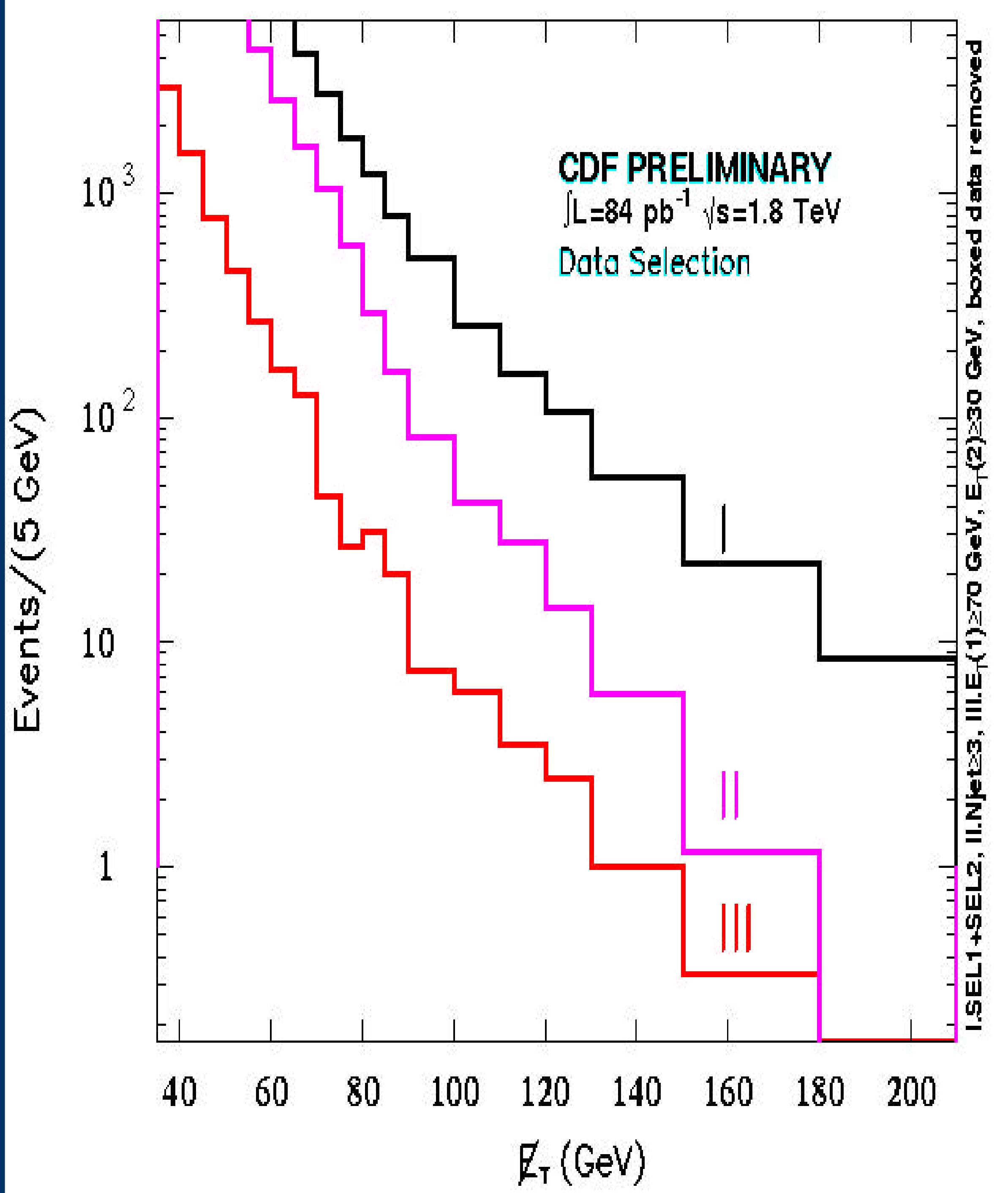
Missing Energy from QCD mismeasurements



Analysis Path

Requirement	Number of Events passing
Pre-Selection and Bad Run veto	286728, (I)
$N_{jet} \geq 3$ (cone .7, $E_T \geq$ 15 GeV)	107509,(II)
Fiduciality fiducial 2nd,3rd jet 2-D $\delta\phi$	 57011 23381
BOX data removed	
$E_T(1) \geq 70$GeV $E_T(2) \geq 30$GeV $\lvert\eta_d\rvert(1\ or\ 2\ or\ 3) < 1.1$	 6435,(III)
EMF(1),EMF(2)$\leq$ 0.9 L2 trigger	6013 4679
$\delta\phi_{min} \geq 0.3$	2737

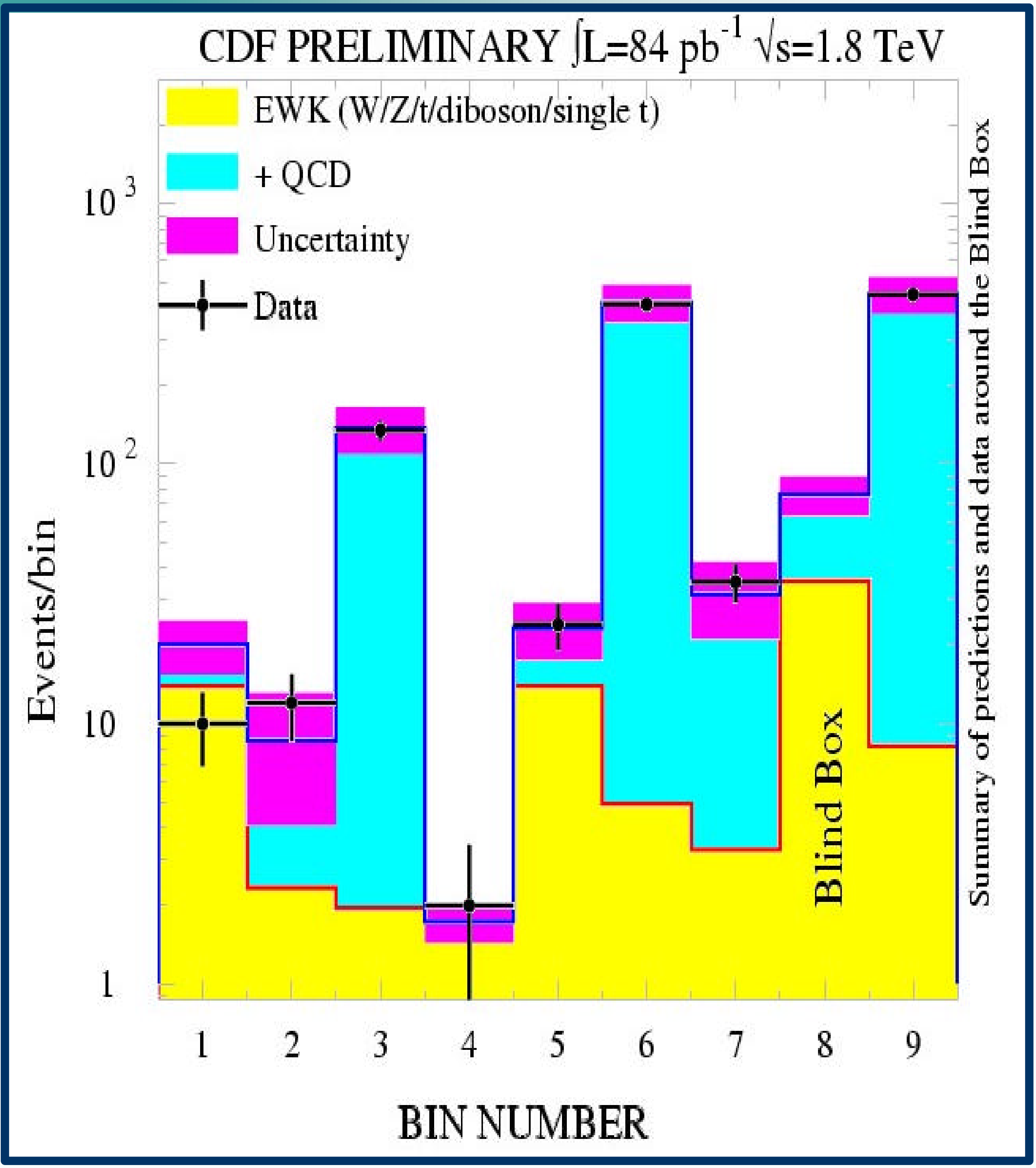
Analysis Path



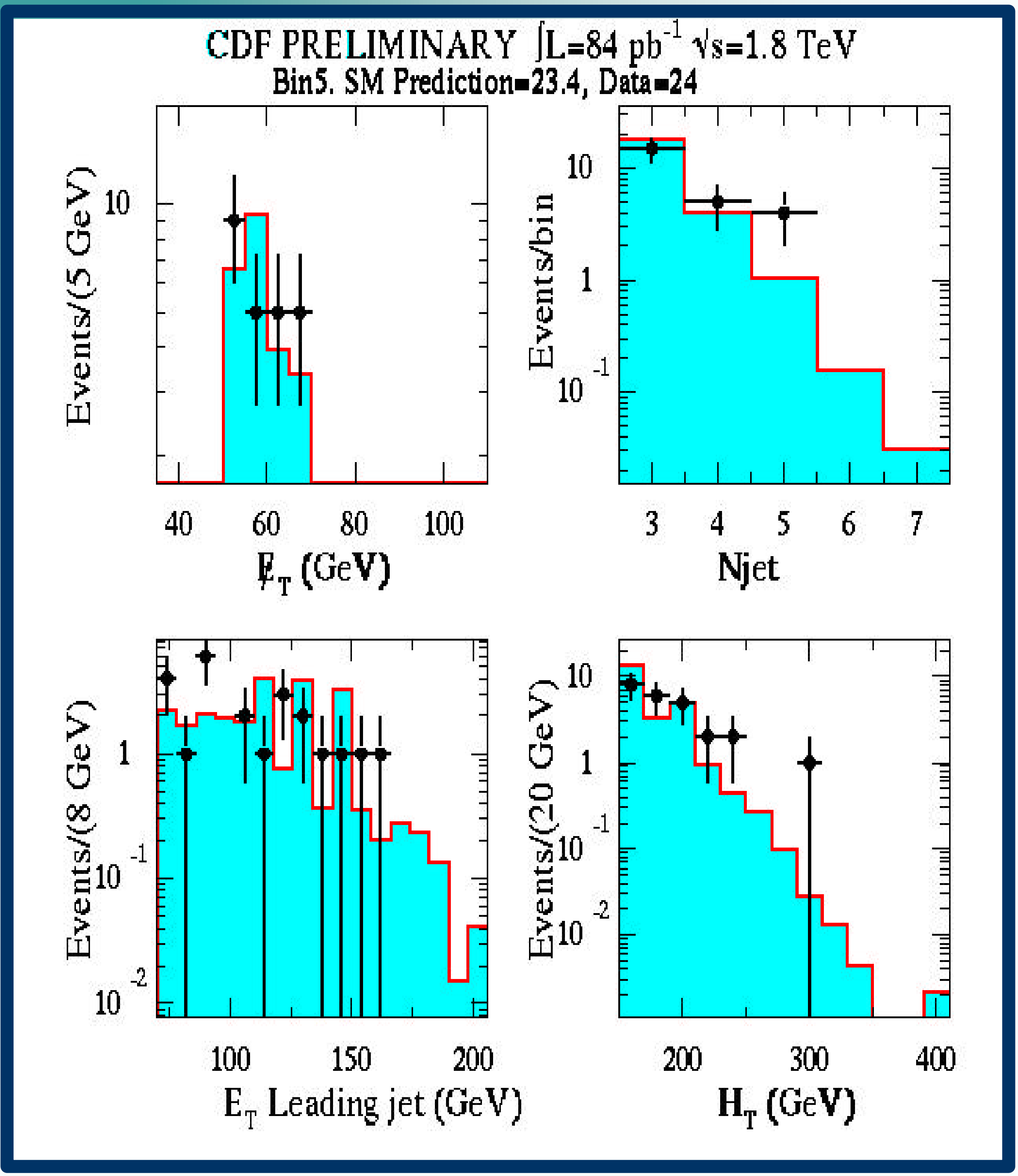
Comparisons SM predictions-Data around the Blind Box

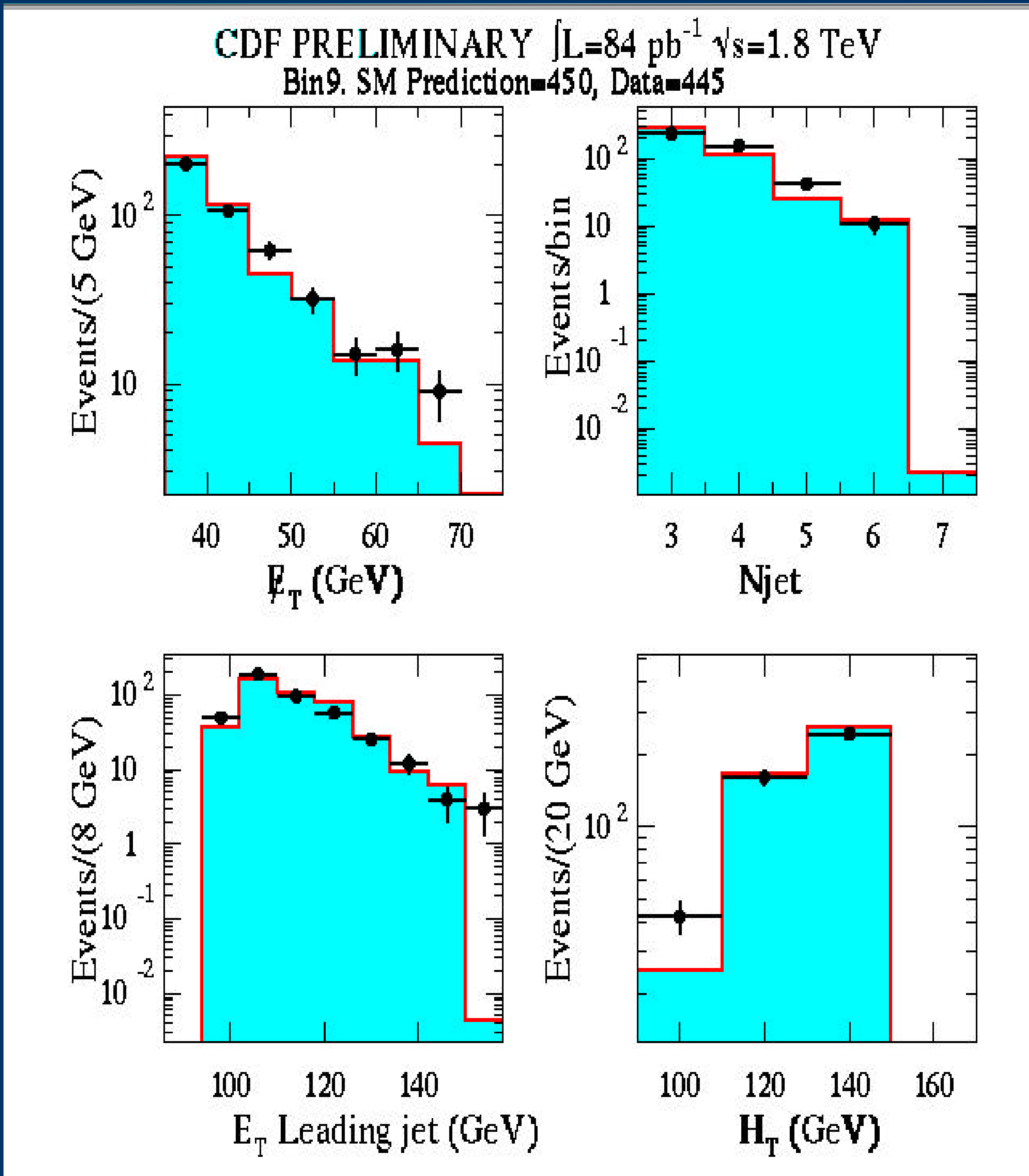
	Description	EWK	QCD	All	Data
1	$\not\!\!E_T \geq 70, H_T \geq 150, N_{trk}^{iso} > 0$	13.9	6.26	20.2±4.7	10
2	$\not\!\!E_T \geq 70, H_T < 150, N_{trk}^{iso} = 0$	2.3	6.26	8.6±4.5	12
3	$35 < \not\!\!E_T < 70, H_T > 150, N_{trk}^{iso} = 0$	1.95	134.6	136.5±27.8	134
4	$\not\!\!E_T > 70, H_T < 150, N_{trk}^{iso} > 0$	1.73	0	1.73±0.3	2
5	$35 < \not\!\!E_T < 70, H_T > 150, N_{trk}^{iso} > 0$	13.95	9.39	23.34±5.7	24
6	$35 < \not\!\!E_T < 70, H_T < 150, N_{trk}^{iso} = 0$	4.9	413.16	418.1±68.8	410
7	$35 < \not\!\!E_T < 70, H_T < 150, N_{trk}^{iso} > 0$	3.3	28.17	31.4±10.2	35
8	$\not\!\!E_T > 70, H_T > 150, N_{trk}^{iso} = 0$	35.3	40.69	76.02±12.8	?
9	$35 < \not\!\!E_T < 70, H_T < 150$	8.2	441.3	449.5±72	445

Comparisons SM predictions-Data around the Blind Box



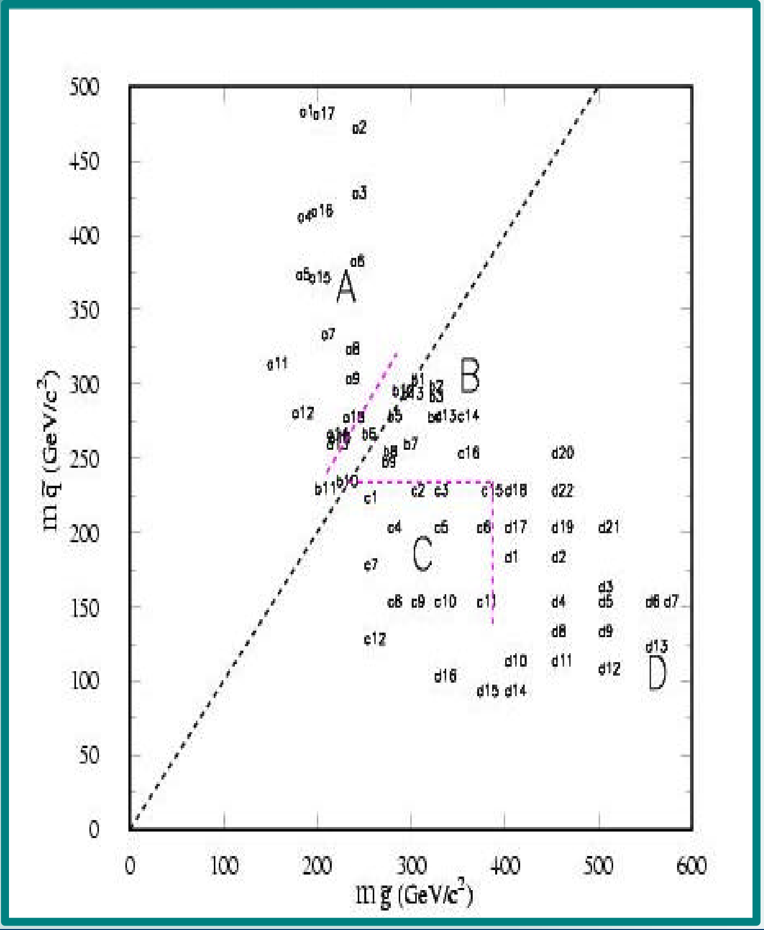
SHAPES AROUND THE BOX (examples)





CDF PRELIMINARY ∫L=84 pb⁻¹ √s=1.8 TeV
Bin9. SM Prediction=450, Data=445
Events/(5 GeV)
Events/bin
Events/(8 GeV)
Events/(20 GeV)
Njet
E_T Leading jet (GeV)
H_T (GeV)

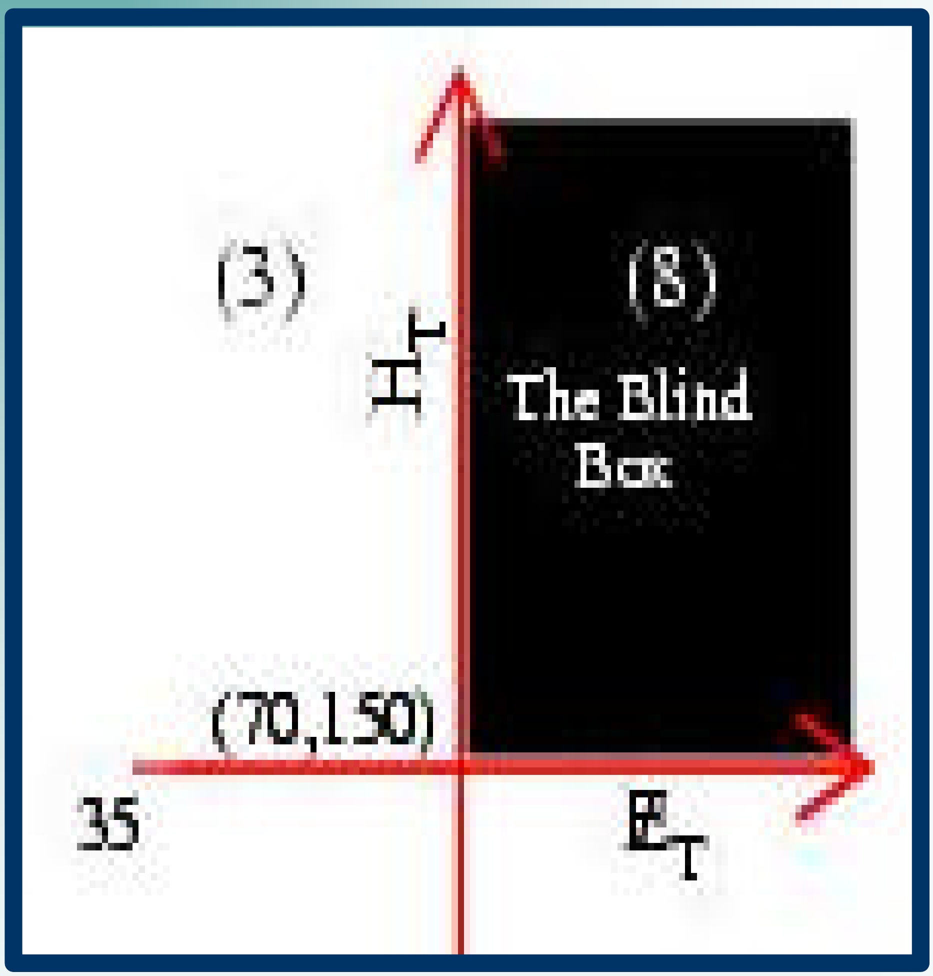
OPTIMAZATION IN SUSY SPACE



Regions	$\not{E}_T$, H_T(GeV)	Standard Model prediction
A/D	90,160	32.7±6.7
B	110,230	3.7±.5
C	110,170	10.6±1

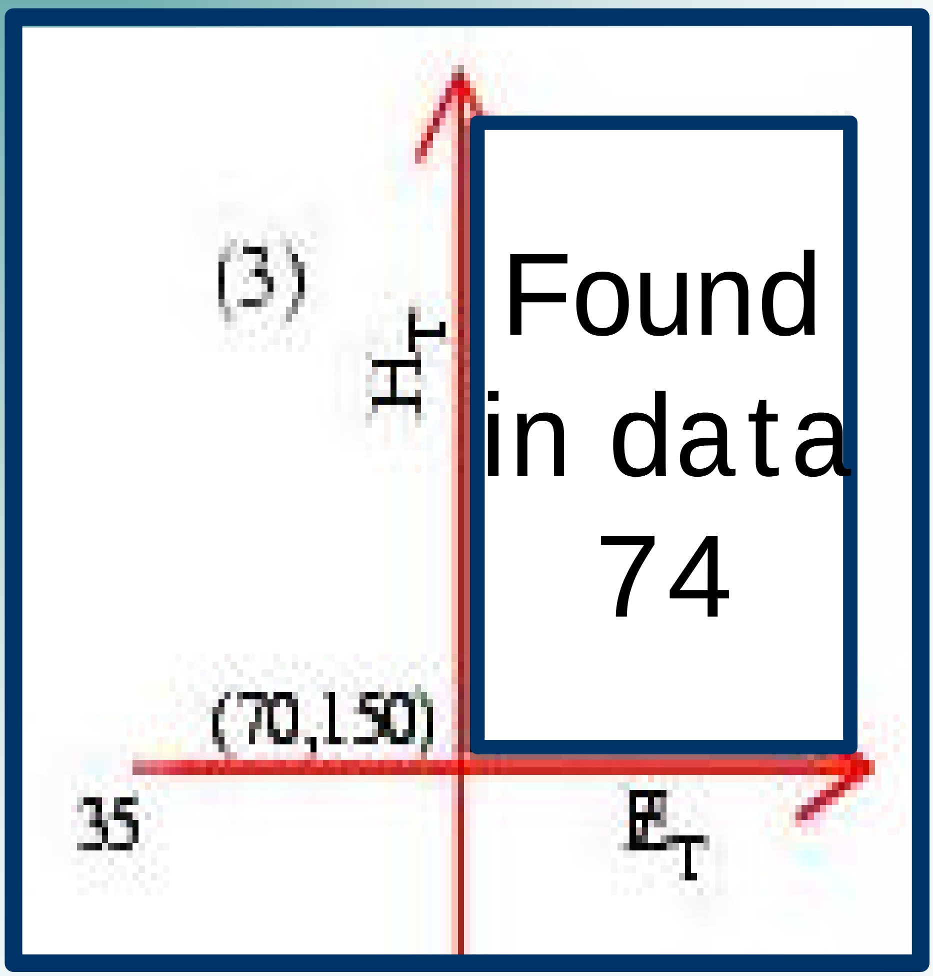
“The BOX”

The Box: SM Expected 76(13)

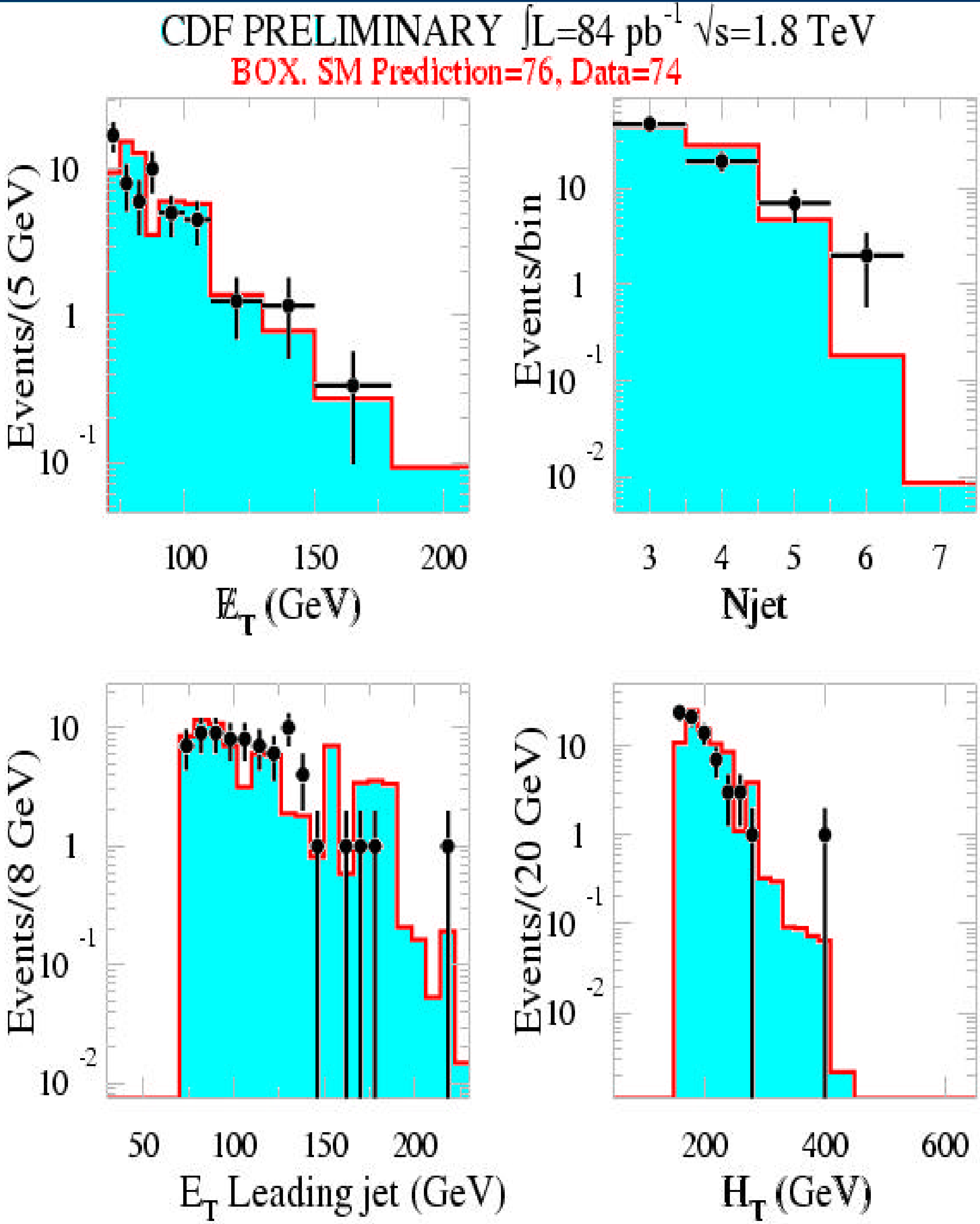


“The BOX”

The Box: SM Expected 76(13)



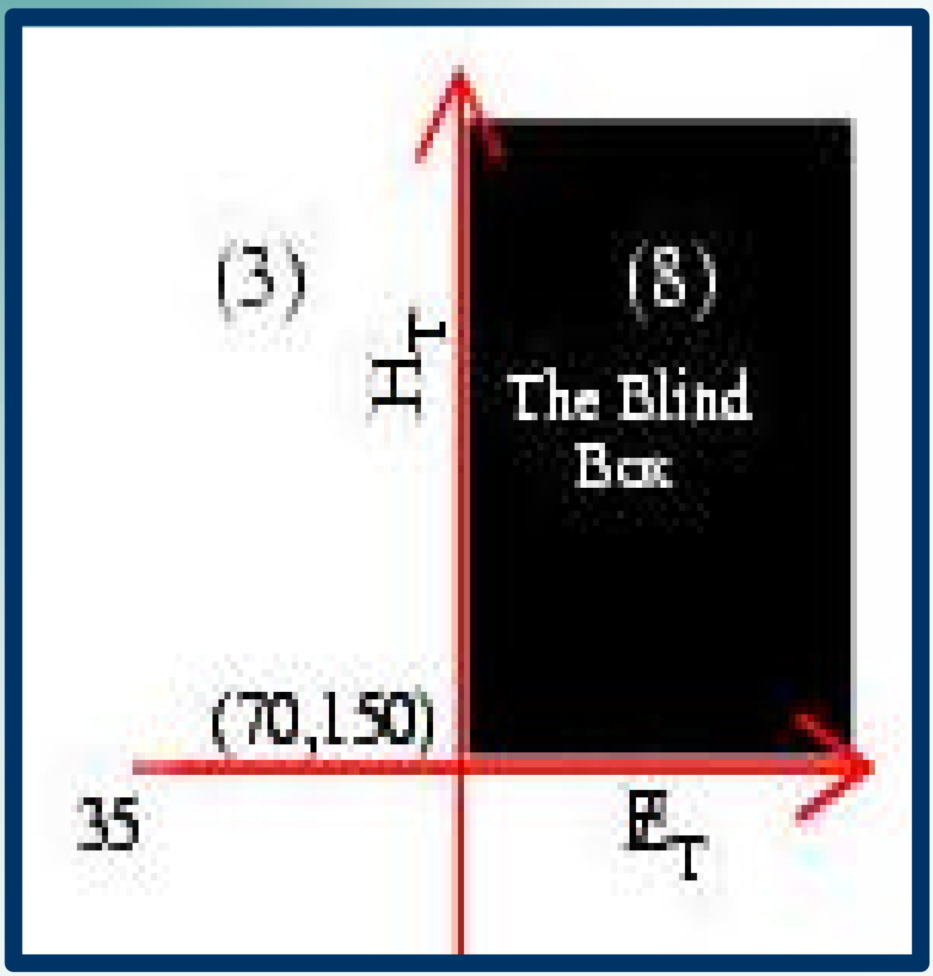
“The BOX”



CDF PRELIMINARY ∫L=84 pb^-1 √s=1.8 TeV
BOX. SM Prediction=76, Data=74
Events/(5 GeV)
10
1
10^-1
100
150
200
E̸T (GeV)
Events/bin
10
1
10^-1
10^-2
3
4
5
6
7
Njet
Events/(8 GeV)
10
1
10^-1
10^-2
50
100
150
200
ET Leading jet (GeV)
Events/(20 GeV)
10
1
10^-1
10^-2
200
400
600
HT (GeV)

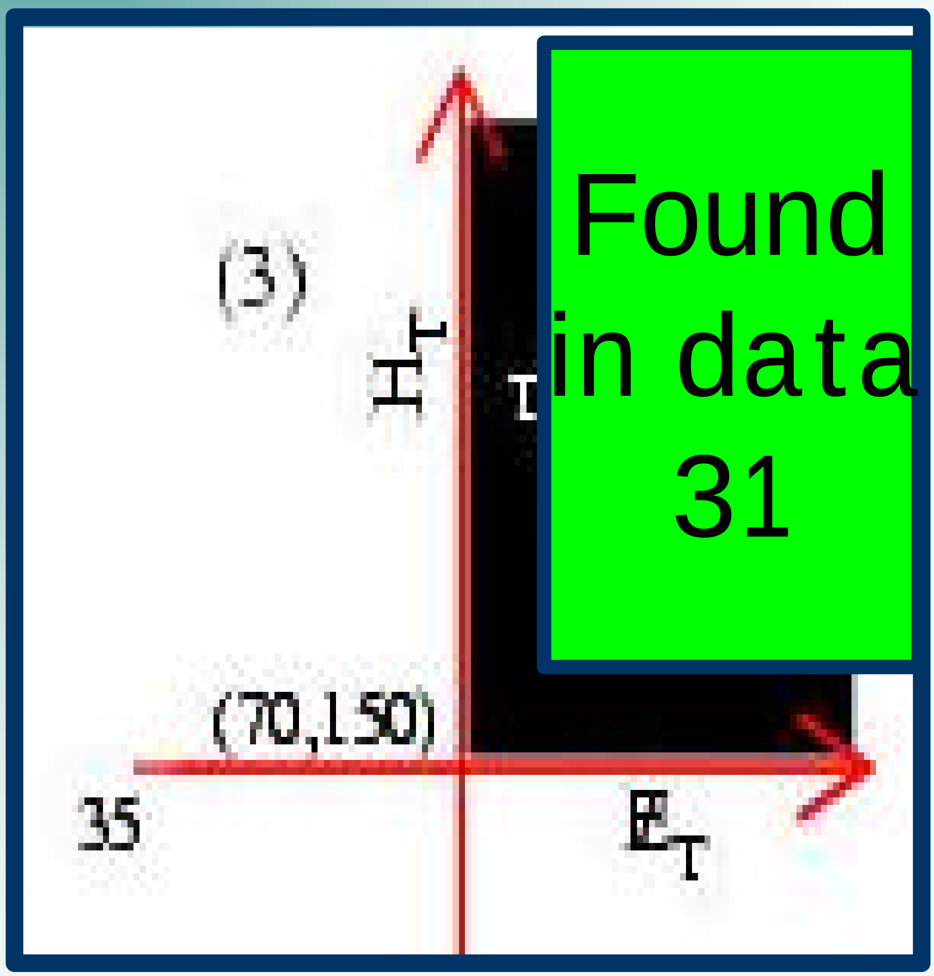
“The other BOXes”

A/D SUSY boxes:
SM Expected 33(7)

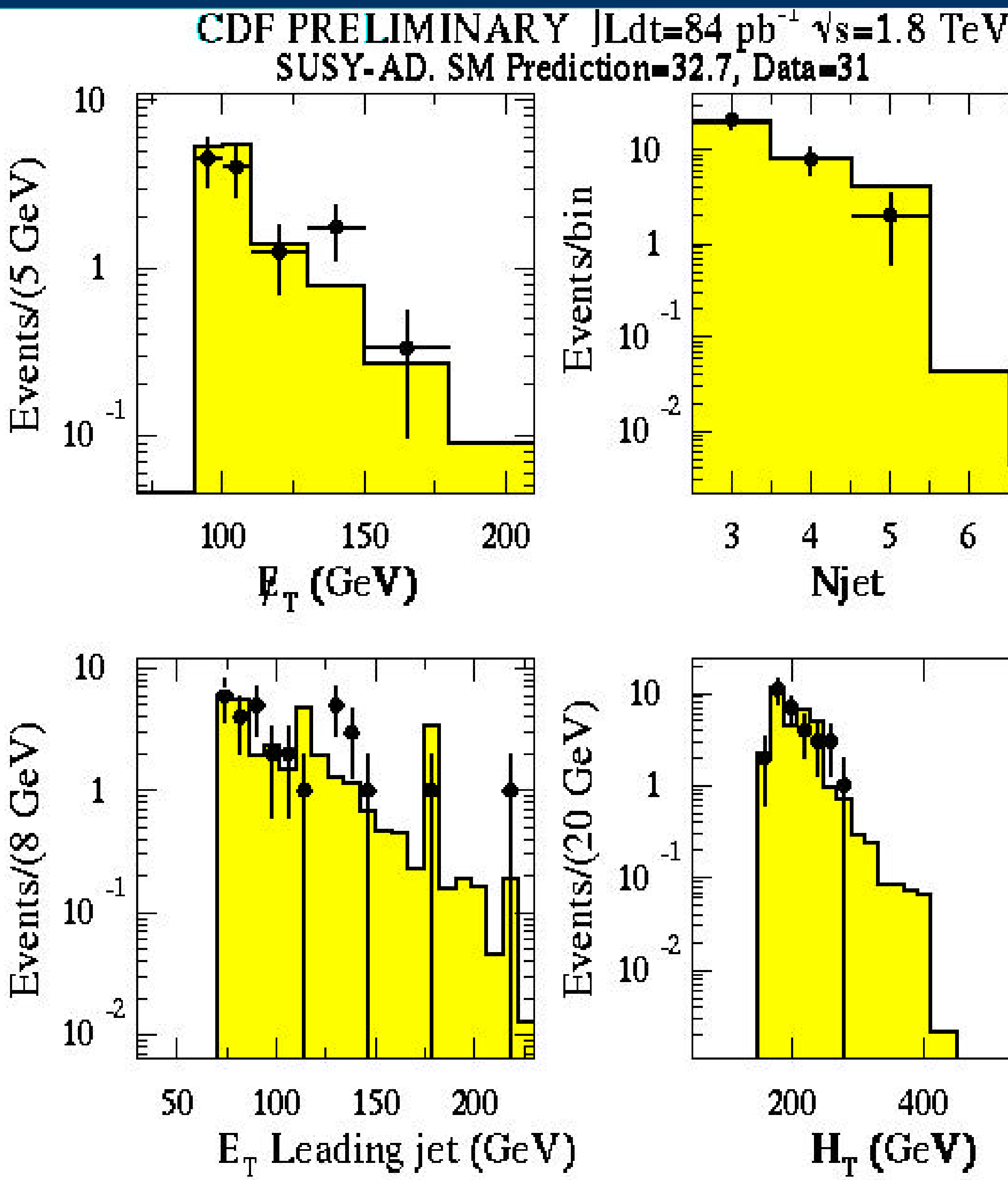


“The other BOXes”

A/D SUSY boxes:
SM Expected 33(7)

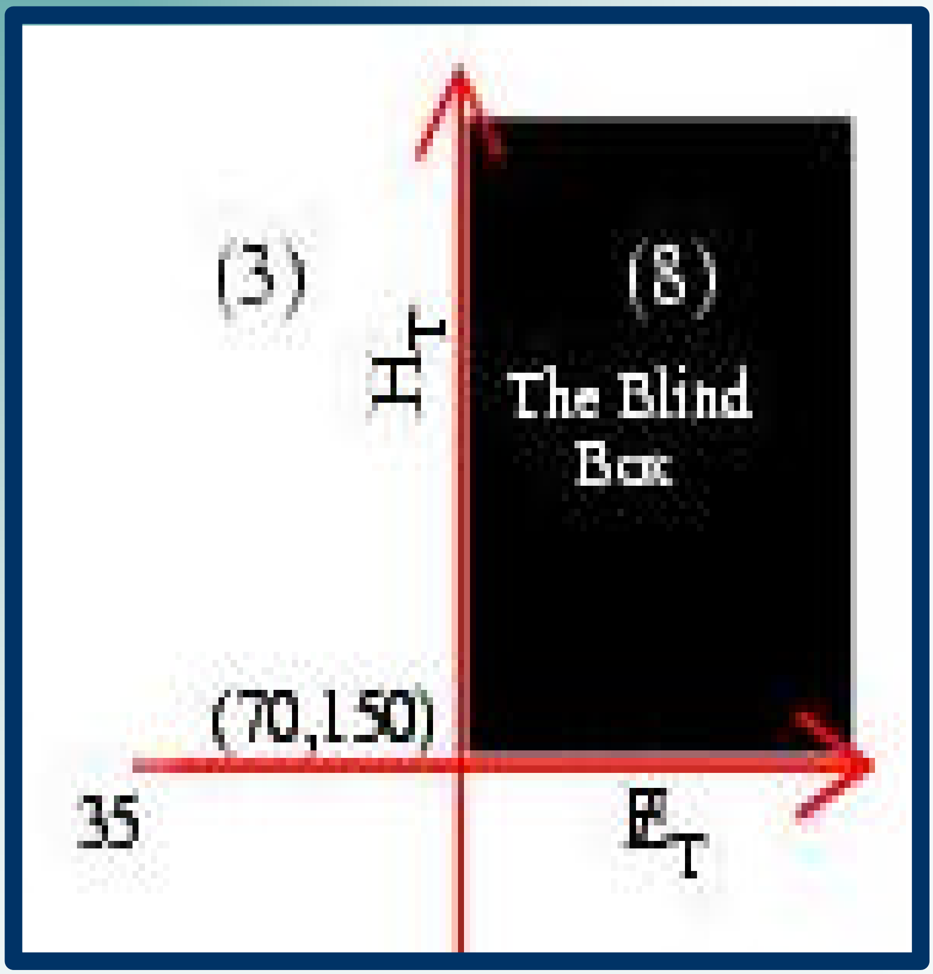


"The other BOXes"



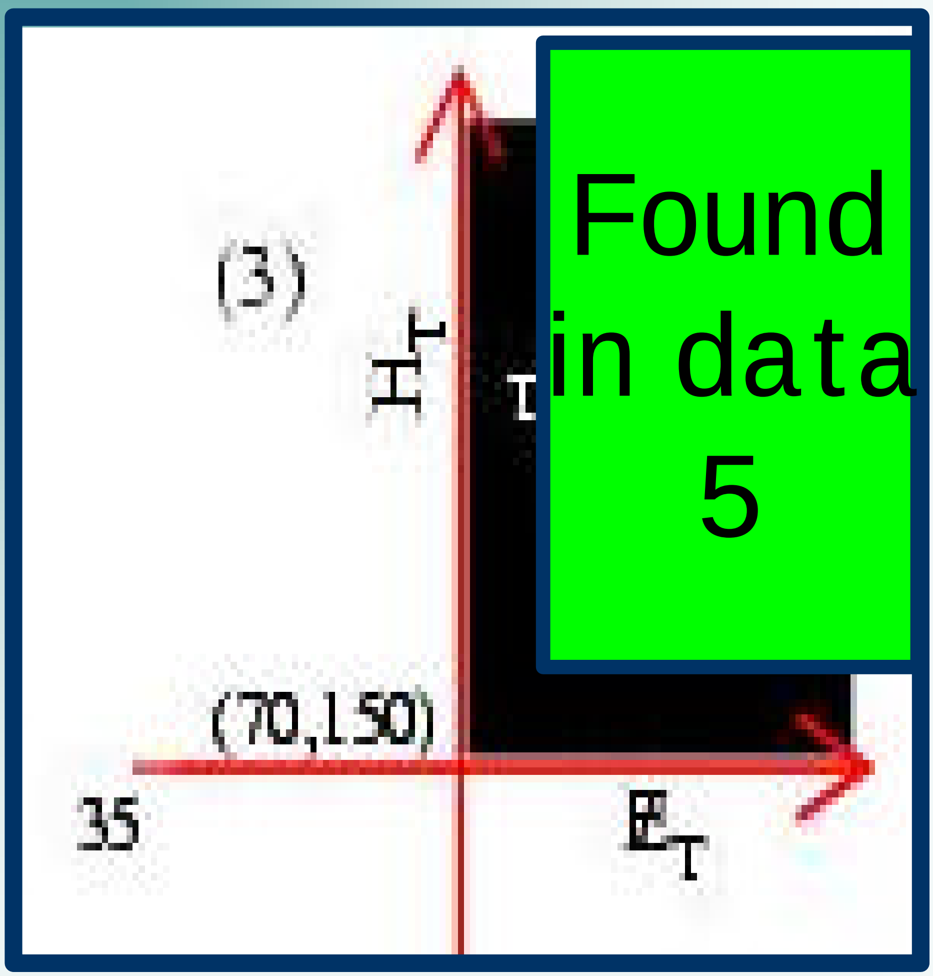
"The other BOXes"

SUSY box B
SM Expected 3.7(0.5)

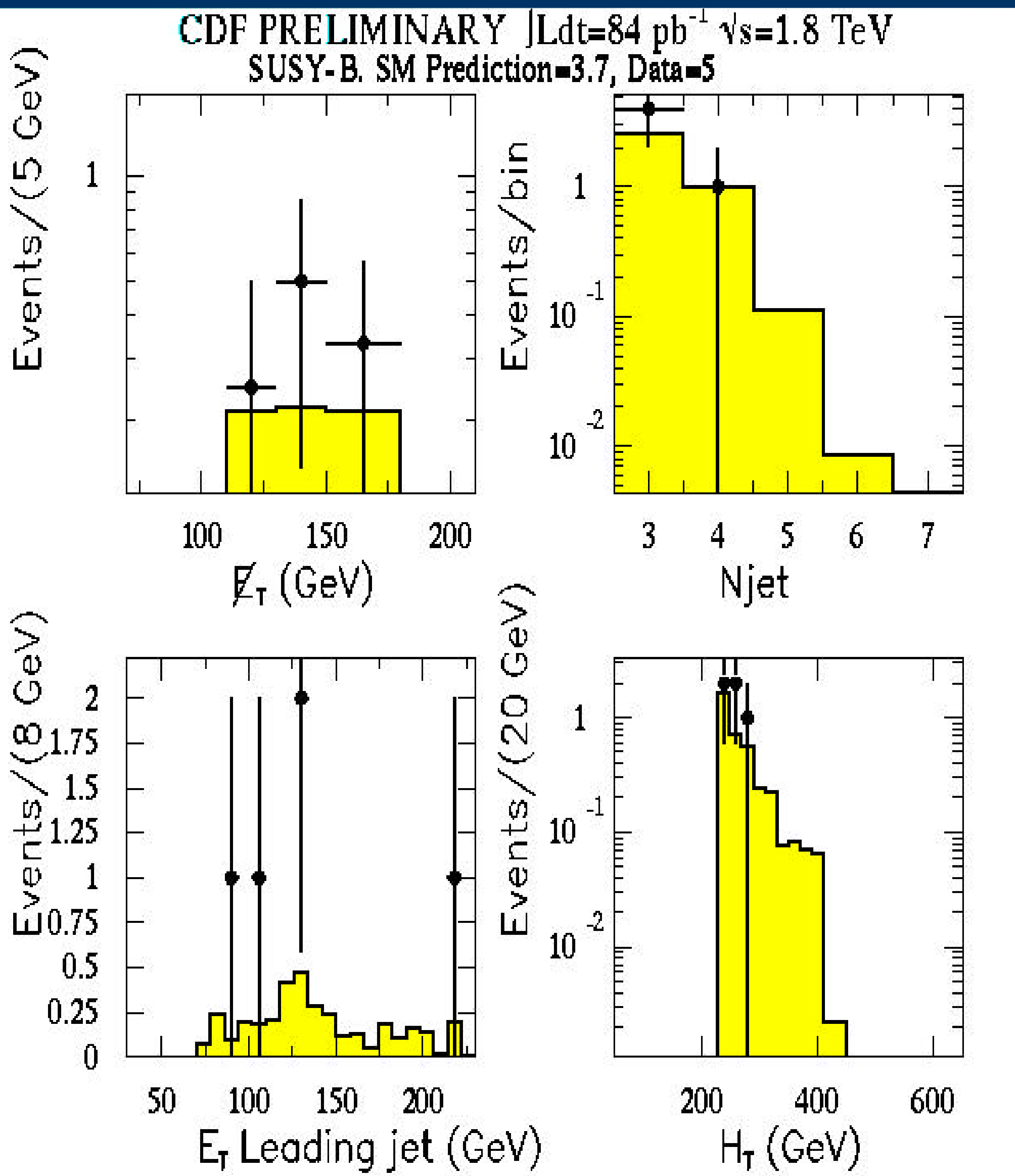


“The other BOXes”

SUSY box B
SM Expected 3.7(0.5)

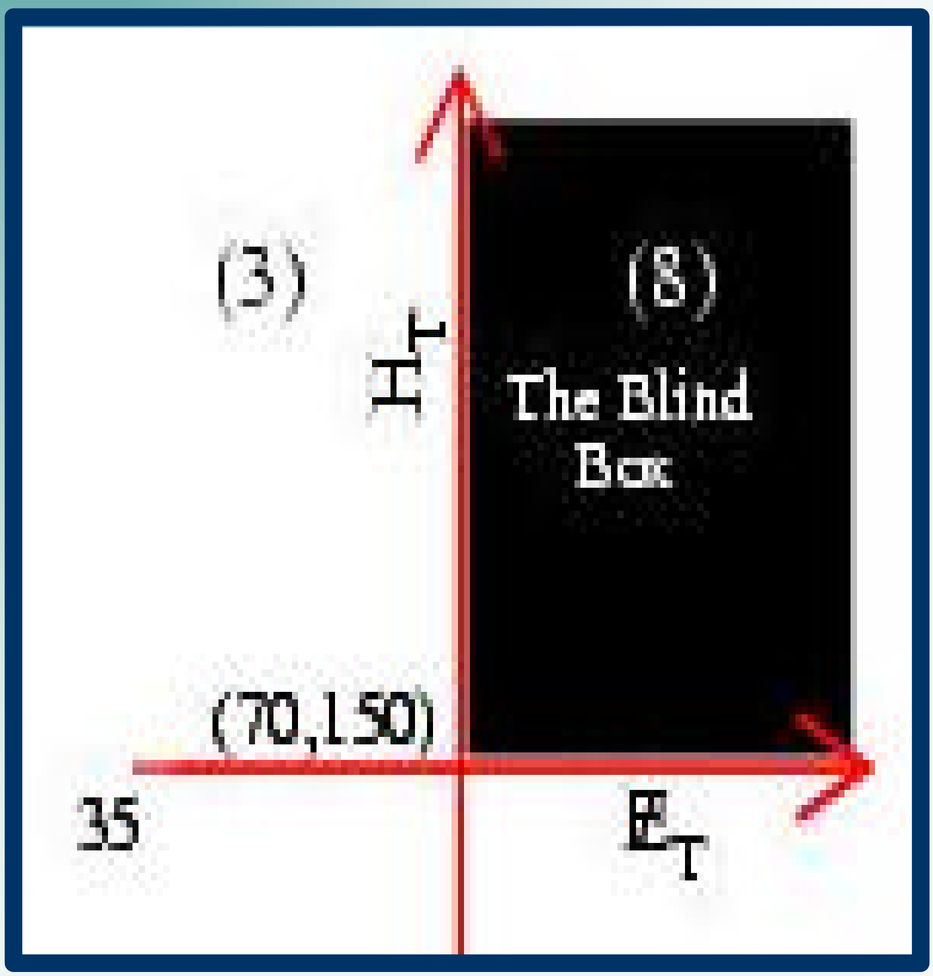


"The other BOXes"



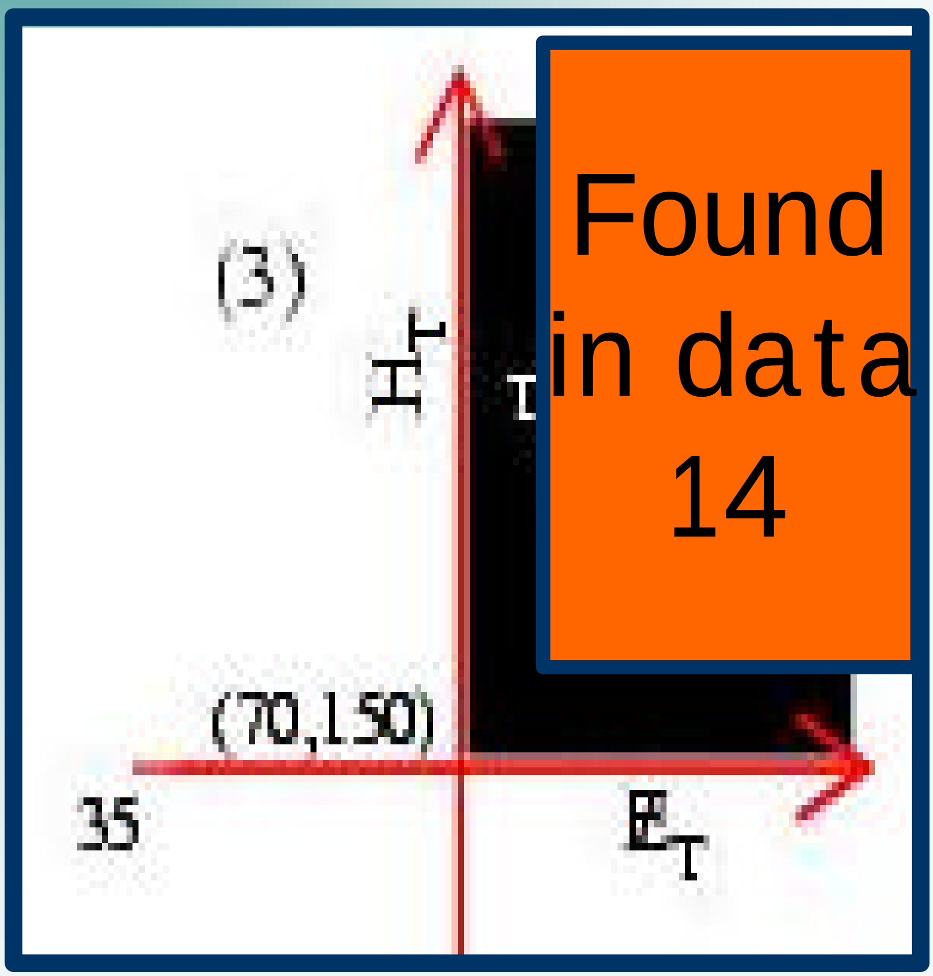
“The other BOXes”

SUSY box C:
SM Expected 10.6(1)

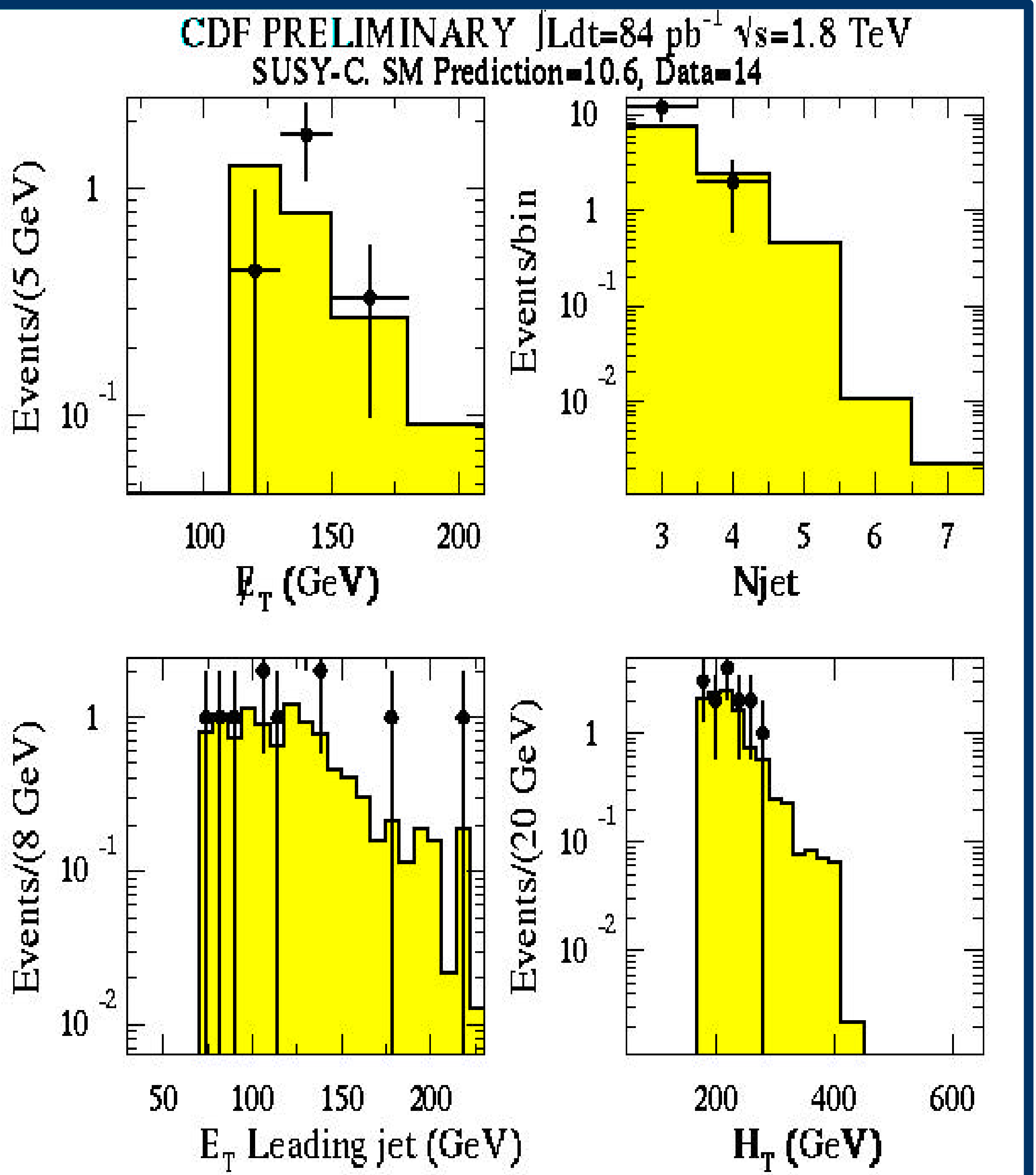


"The other BOXes"

SUSY box C:
SM Expected 10.6(1)



"The other BOXes"

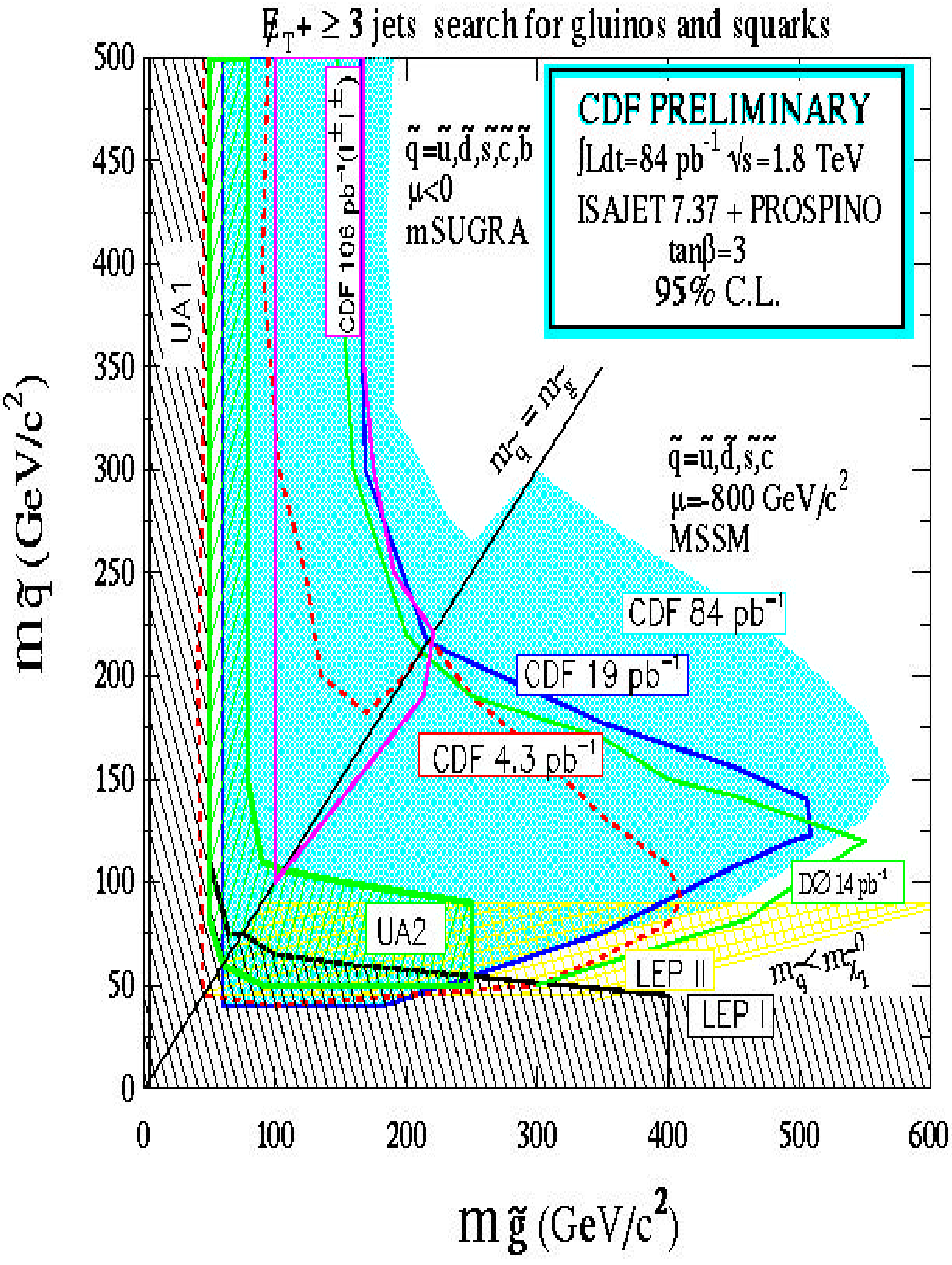


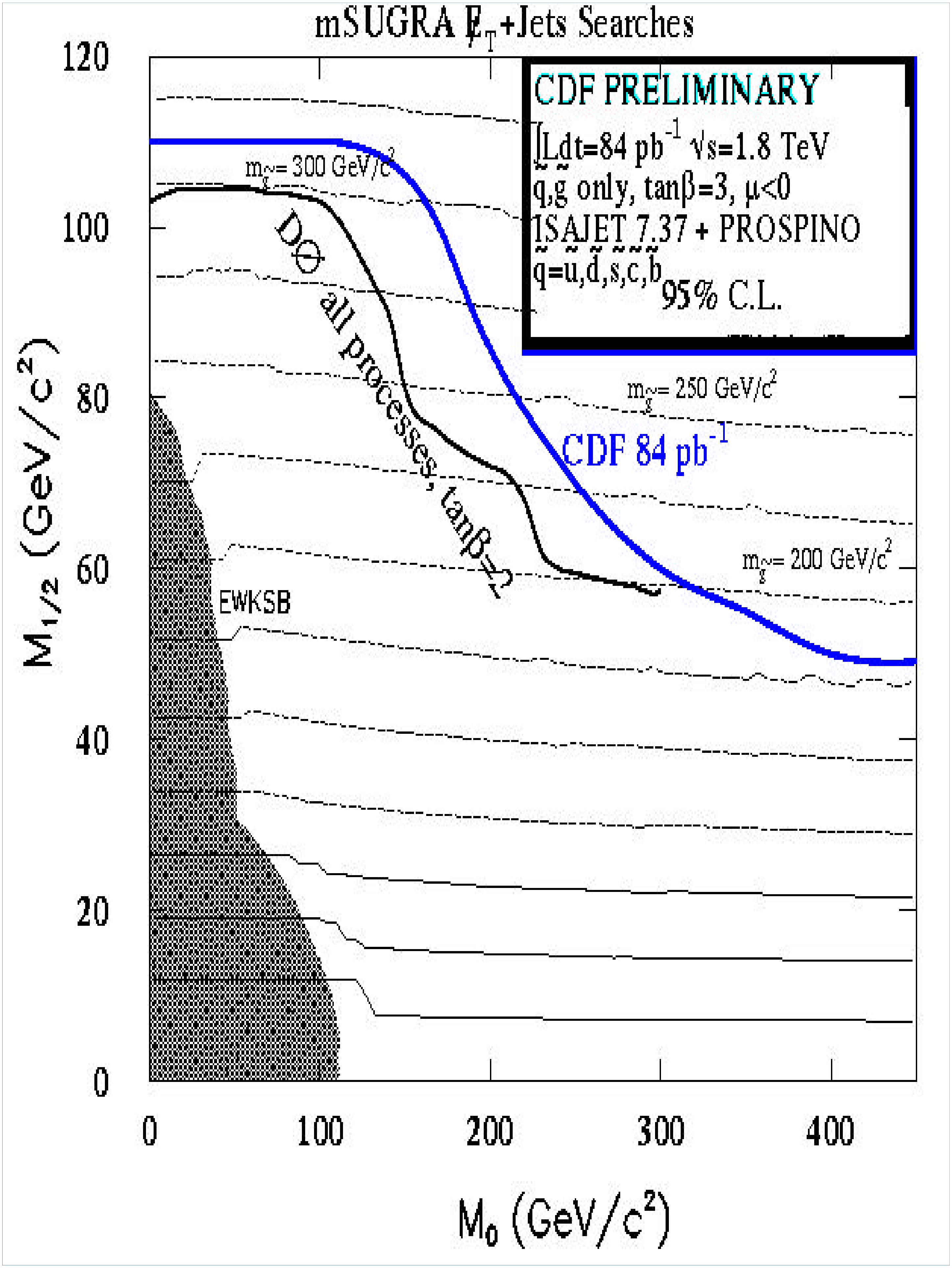
Box	MET,HT	Expected	Observed	$N_{95\%C.L.}$
A	90,160	32.7 ± 6.7	31	17.7
B	110,230	3.7 ± 0.5	5	7.4
C	110,170	10.6 ± 1	14	11.9
D	90,160	32.7 ± 6.7	31	17.3

% Overall Relative Uncertainty on Signal Acceptance

ind	a16	a14	b13	b4	d18	d6
% <PDFs>	6.5	3.5	5.5	4	3	5
% max(Radiation)	12.5	6	3	4	3	3
% $max(Q^2)$	6.5	6.5	5.5	5.5	4	9
% <JET>	4.5	3.5	6	6	3	4
% Trigger	2					
% MC stat.	<0.2					

	A	B	C	D
σ_A%	15	11	11	10


$\not\!E_T + \geq 3$ jets search for gluinos and squarks
CDF PRELIMINARY
$\int Ldt = 84\ pb^{-1}$ $\sqrt{s} = 1.8$ TeV
ISAJET 7.37 + PROSPINO
$\tan\beta = 3$
95% C.L.
$\tilde{q} = \tilde{u}, \tilde{d}, \tilde{s}, \tilde{c}, \tilde{b}$
$\mu < 0$
mSUGRA
CDF 106 pb^{-1} $(l^{\pm} l^{\pm})$
UA1
$m_{\tilde{q}} = m_{\tilde{g}}$
$\tilde{q} = \tilde{u}, \tilde{d}, \tilde{s}, \tilde{c}$
$\mu = -800$ GeV/c^2
MSSM
CDF 84 pb^{-1}
CDF 19 pb^{-1}
CDF 4.3 pb^{-1}
DØ 14 pb^{-1}
UA2
LEP II
LEP I
$m_{\tilde{q}} < m_{\tilde{\chi}_1^0}$
$m_{\tilde{q}}$ (GeV/c^2)
$m_{\tilde{g}}$ (GeV/c^2)
0
50
100
150
200
250
300
350
400
450
500
600



mSUGRA $\not{E}_T$+Jets Searches
CDF PRELIMINARY
$\int L dt = 84\ pb^{-1}$ $\sqrt{s}=1.8$ TeV
$\tilde{q},\tilde{g}$ only, $\tan\beta=3$, $\mu<0$
ISAJET 7.37 + PROSPINO
$\tilde{q}=\tilde{u},\tilde{d},\tilde{s},\tilde{c},\tilde{b}$
95% C.L.
$m_{\tilde{g}}$= 300 GeV/c^2
$m_{\tilde{g}}$= 250 GeV/c^2
$m_{\tilde{g}}$= 200 GeV/c^2
DØ all processes, $\tan\beta=2$
CDF 84 pb^{-1}
EWKSB
$M_{1/2}$ (GeV/c^2)
M_0 (GeV/c^2)
0
20
40
60
80
100
120
0
100
200
300
400

For $m_{\tilde{q}} \approx m_{\tilde{g}}$ $m < 300$ GeV/c^2

For $m_{\tilde{q}} \ll m_{\tilde{g}}$ $m_{\tilde{g}} < 570$ GeV/c^2

For $m_{\tilde{q}} \gg m_{\tilde{g}}$ $m_{\tilde{g}} < 195$ GeV/c^2

Phenomenological Implications/Discussion

If the sparticles are too heavy then SUSY requires fine tuning and the hierarchy problem reappears. How much fine tuning is tolerable determines how probable low energy supersymmetry is and how soon it will be discovered.

It has been recently pointed out (Bastero-Gil et al./ Dimopoulos et al.) that the electroweak scale looks more natural if M_3 is relatively small.

Phenomenological Implications/Discussion

$$M_Z^2 = -1.7\mu^2 + 7.2M_3^2 - 0.24M_2^2 + 0.014M_1^2 + \ldots$$

The required cancellation is easier if the gluino mass is not so big.

$$M_3 \geq 300 \rightarrow \frac{7.2M_3^2}{M_Z^2} \geq 80$$

With gaugino mass unification
M_1:M_2:M_3::0.5:1:3.3
The result of this analysis as well as the LEP result on the chargino M_2<90 GeV make it interesting to drop gaugino unification and allow lower gluino mass.

Phenomenological Implications/Discussion

If low energy supersymmetry exists and given that the amount of fine tuning depends critically on the gluino mass, this result indicates that RUNII and the missing energy + jets channel (with lepton veto) constitute a very good probe and have discovery potential.

Candidate Event